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STRENGTH AND DYNAMIC CHARACTERISTICS OF GASKET-JOINTED CONCRETE WATER PIPELINES

By

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16. Abstract (Limit: 200 words)

This study extends to gasket-jointed concrete water-pipelines the information given in previous reports on cast-iron pipelines. Types of concrete pipe and their usage are included; however, prestressed concrete cylinder pipe and prestressed concrete embedded cylinder pipe are discussed in detail. Since only straight jointed pipelines are considered, the effects of major changes in the direction of the pipeline are ignored. A description of the actual performance of some existing concrete pipelines including dates of installation and types of failure, is included. Some test data on pipes and joints are considered. The general design methods used by the manufacturing industry are illustrated by means of examples. A brief review of the recommendations on pipe design by the Bureau of Reclamation and the American Water Works Association is given. The authors briefly discuss some of the criteria concerning state-of-the-art design. More tests supported by Federal funds are recommended so that adequate design criteria for pipelines can be established.

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Dynamic characteristics	Stress analysis	Gaskets
Pipe joints	Elastic properties	

b. Identifiers/Open-Ended Terms

Concrete water pipelines

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I

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Strength and Dynamic Characteristics

of

Gasket-Jointed Concrete Water Pipelines

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I. SCOPE

The purpose of this report is to extend to gasket-jointed concrete water-pipelines the information given in Weidlinger Associates (WA) previous reports IR-3 and IR-3a on cast-iron pipelines.

The report consists of 10 parts dealing with the following topics:

I. Scope.

II. Types of concrete pipe and their usage.

III. Specifications.

IV. Reinforced concrete and prestressed concrete pipe design.

V. Pipe and joint behavior (static and dynamic).

VI. Ultimate material strengths and damage matrices.

VII. State of the art of pipe design.

VIII. Conclusions and recommendations.

IX. Acknowledgements.

X. Bibliography (subdivided by sections).

Since the research based on NSF Grant No. 76 has the fundamental purpose of establishing a methodology for the study of earthquake effects on pipelines, this report, while generally describing the most commonly used types of concrete pipes, deals in detail with only two such types: the prestressed concrete cylinder pipe (PCC) and the prestressed concrete embedded cylinder pipe (PCEC). As in the preceding reports, only straight jointed pipelines are considered. Hence, the effects of major changes in the direction of the pipeline, requiring special connectors and fittings, and anchorage blocks are ignored.

A description of the actual performance of some existing concrete pipelines, including dates of installation and types of failure, is included. Available test data on pipes and joints is considered, even though it is very scant.

The general design methods used by the manufacturing industry are illustrated by means of examples and a brief review of the recommendations on pipe design by the Bureau of Reclamation (BuRec) and the American Water Works Association (AWWA) is given.

II. TYPES OF CONCRETE PIPE AND THEIR USAGE

1. Concrete pipe classification and uses.

The most concise and clear classification of concrete pressure-pipe into 6 categories is given in "Installation of Concrete Pipe" (AWWA No. M9), and is here reproduced on pages 3-7.

Of the 6 types mentioned in AWWA No. M9 the "Noncylinder Concrete Pipe, Prestressed (PC)" is seldom if ever used in the United States. For simplicity of reference the other 5 types have been labeled as follows in this report:

a) Noncylinder Nonprestressed Concrete Pipe = RC

b) Nonprestressed Concrete Cylinder Pipe = RCC

c) Pretensioned Concrete Cylinder Pipe = RCCP

d) Prestressed Concrete Cylinder Pipe = PCC

e) Embedded Cylinder Prestressed Concrete Pipe = PCEC

The first 3 types use only reinforcing bars, while the last 2 types use prestressing wire, and reinforcing bars only locally.

2. Geometrical characteristics

The following figures 6-10 and Tables I-V give the geometrical and physical,

(cont'd on p.13)

1. Purpose and Scope

THE last 20 years of the 50-year history of the concrete pipe industry have been characterized by a rapid increase in the use of concrete pressure pipe in the water supply field. This trend has been brought about by improvements in design and manufacturing and by the introduction of new types of pipe.

Many persons in the water supply field are not familiar with the various kinds of concrete pressure pipe that are available today and with methods that are in use for handling and installing the pipe. The purpose of this report is to provide descriptions of available concrete pressure pipe and suggestions for installation based on experience in various parts of the United States. The report includes the procedures used in layout, transportation, trenching, installation, backfilling, special construction, field testing, sterilization, and making taps and connections. It is not intended to provide standards or specifications for the design, manufacture, or installation of concrete pressure pipe.

Much of the information contained in this report has been published previously in the form of descriptive articles on specific installations and in instructions published by manufacturers of concrete pressure pipe. The members of AWWA Committee 8320 D—Reinforced Concrete Pipe, however, believe that there is a need for presenting this information in a single document.

2. Description of Concrete Pressure Pipe

The types of concrete pressure pipe now manufactured are relatively new. Their use, however, has increased at a rapid rate in all parts of the United States.

The first reinforced concrete steel cylinder pressure pipeline was a 36-in. diameter line constructed at Cumberland, Md., in 1919. Prestressed concrete steel cylinder pipe was first used for water service in the United States in 1942. Since that time, many millions of feet of the pipe have been manufactured and installed in this country. In the western and southwestern parts of the United States, a type of concrete pressure pipe generally known as pretensioned concrete

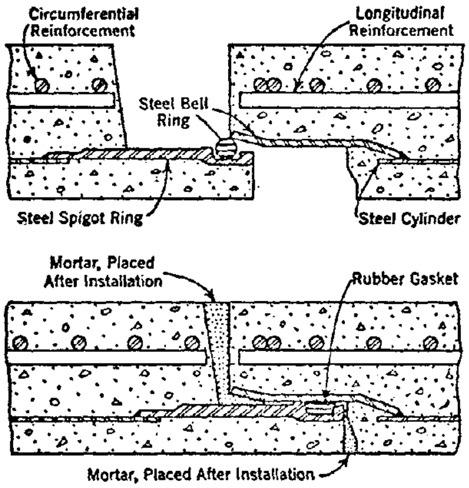


Fig. 1. Cross Section of Nonprestressed Concrete Cylinder Pipe and Joint RCC

The concrete both within and outside the steel cylinder is applied by vertical casting and vibration. Curing is done by means of water or steam. Mortar is placed after installation.

cylinder pipe has been used extensively for a number of years. Another type that has been used, principally for low-pressure lines, is noncylinder concrete pressure pipe that is not prestressed. Within the past 20 years, prestressed concrete pipe that does not contain a cylinder has been developed and used principally outside of the United States.

Nonprestressed Concrete Cylinder Pipe RCC

From 1920 to about 1940, most of the concrete pressure pipe used in the United States by the water supply industry was steel cylinder concrete pipe that was not prestressed. More than 12,000,000 ft of this pipe has been installed to date. It is manufactured in sizes ranging from 2 ft to more than 12 ft in diameter and for working pressures as high as about 260 psi.

Nonprestressed concrete cylinder pipe, as manufactured today, consists of a welded steel sheet or steel plate cylinder with steel joint rings welded to its ends; a reinforcing cage or cages of steel rods or bars surrounding the cylinder; a wall of dense concrete covering the steel cylinder inside and out; and a preformed gasket of rubber for providing the joint seal (Fig. 1). Each steel cylinder, with joint rings attached, is tested hydrostatically for watertightness before it is encased in concrete. Prior to about 1935, a preformed lead gasket, calked from the inside, was used instead of a rubber gasket.

The concrete inside and outside the cylinder is applied by vertical casting and mechanical vibration. Curing is accomplished by means of water or steam. The pipe generally is made

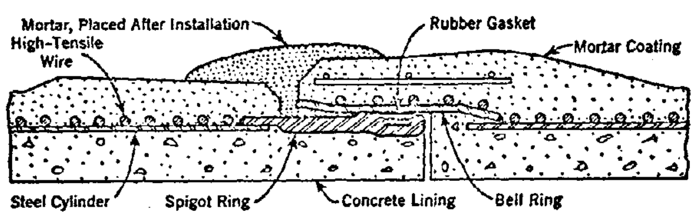


Fig. 2. Lined-Cylinder Prestressed Concrete Pipe and Joint PCC

The cylinder is lined centrifugally with dense concrete, and high-tensile wire is wrapped around the steel cylinder. The wrapped core is then covered with a mortar coating. Joint mortar is placed after installation.

in 12-, 16-, or 20-ft lengths. The circumferential steel of the cage provides about 40–80 per cent of the reinforcement.

Prestressed Concrete Cylinder Pipe PCC

Prestressed concrete cylinder pipe was first produced in the United States in 1942 for the cities of Penniman, Va., and Hyattsville, Md. Because of its many advantages, including low cost of production and excellent performance under various internal pressures and external loading conditions, it has rapidly gained favor with the water supply industry. Since 1942, about 16,000,000 ft of this pipe, 16–120 in. in diameter, has been manufactured in the United States.

The two general types of prestressed concrete steel cylinder pipe are: (1) pipe with a steel cylinder lined with a concrete core, and (2) pipe with a steel cylinder embedded in a concrete core. The first or original type is supplied with diameters of 16–48 in. and is designed for pressures as high as 250 psi. The embedded-cylinder type, which was developed later, is generally available with diameters of 24–72 in. and is designed for pressures as high as 350 psi. Pipe with larger diameters has been constructed. Fig. 2 shows a closed section of the joint of a typical lined-cylinder prestressed concrete steel cylinder pipe.

The welded steel cylinder with joint rings attached is made and tested in the same manner as the nonprestressed cylinder pipe. It is then lined centrifugally with dense concrete by a method that rapidly revolves the pipe in a horizontal position. The lined cylinder is cured, and high-tensile wire is wrapped around the core directly on the steel cylinder. The tension of the wire is measured accurately and constantly to produce a predetermined residual compression in the core. Spacing and size of wire are determined by design requirements. The wrapped core is then covered by a dense, premixed mortar coating about ¾ in. thick, applied by an impact method.

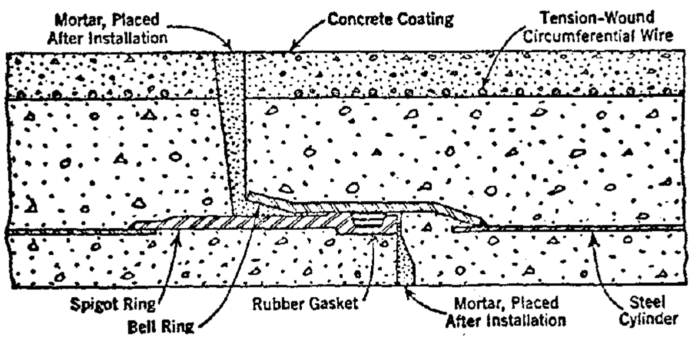


Fig. 3. Embedded-Cylinder Prestressed Concrete Pipe and Joint PCEC

In this type of pipe, the tension-wound wire, instead of being wrapped around the steel, is wrapped around a concrete core in which the steel cylinder is embedded.

A recent development in prestressed cylinder pipe is the embedded cylinder, a section of which is shown in Fig. 3. The cylinder and joint rings for embedded-cylinder pipe are constructed in the same manner as for the other types of cylinder pipe. The completed cylinder with joint rings is then embedded in concrete by vertical casting. After the concrete is cured, the wire reinforcement is wound around the outside of the concrete core that contains the cylinder, instead of being wound directly on the cylinder. An exterior coating of premixed mortar is applied by an impact method or by the vertical-casting method. This type of construction has been found to be superior for large-diameter pipe and for pipe designed for comparatively high pressures.

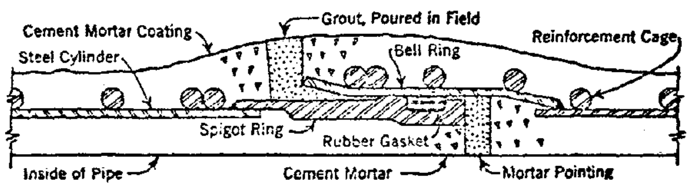


Fig. 4. Pretensioned Concrete Cylinder Pipe and Joint RCCP

Although similar to lined-cylinder prestressed concrete pipe (Fig. 2), pretensioned concrete cylinder pipe is lighter and less costly. It is not as rigid as the former kind of pipe and is used primarily in places where it is not likely to undergo extreme external loads.

Pretensioned Concrete Cylinder Pipe RCCP

Pretensioned concrete cylinder pipe (Fig. 4) is manufactured and used for moderate- and high-pressure service in the western and southwestern parts of the United States. The steel cylinder may be formed as a helically welded tube or as a tube with longitudinal seams. The steel joint rings are attached in the same general manner as for other types of concrete pressure pipe. The steel used for the cylinder is generally heavier, size for size and class for class, than that used for other types of concrete pipe with steel cylinders. The cylinder is lined with cement mortar 0.5 in. thick on 16-in. and smaller pipe, and 0.75 in. thick on 18-in. and larger pipe. Reinforcing rods are then wound under measured tension around the lined cylinder. To complete the pipe, a 0.75-in. mortar coating (measured from the rod) is applied by means of mechanical or pneumatic projection.

This type of pipe generally is made with diameters of 10–36 in. and is available with diameters as large as 72 in. The pipe sections are usually 32 ft long and lighter in weight than vertically cast pipe of the same size.

Pretensioned concrete pipe is a semirigid pipe. It deflects slightly from external loads. Care should be exercised in providing proper bedding and backfill, particularly with sizes greater than 36 in. ID. These are important factors in developing the full external-load carrying capacities of this type of pipe.

Noncylinder Concrete Pipe, Nonprestressed – RC

Noncylinder pipe that is not prestressed has been used extensively in the water supply industry for low-head transmission lines. It generally is not used where internal pressures are greater than about 45 psi. It is made with a rubber and steel joint, although a similar type of joint with concrete forming the bell and spigot is sometimes used. It is made with either one or more reinforcing cages and with diameters of 12–144 in. Concrete generally is applied centrifugally or by vertical casting. Figure 5 shows a section of this type of pipe with two reinforcing cages and a rubber and steel joint.

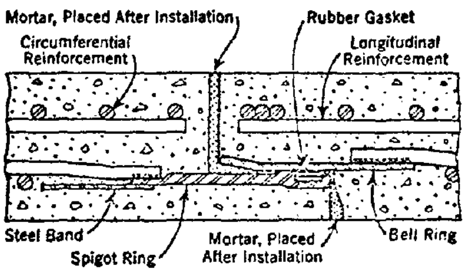


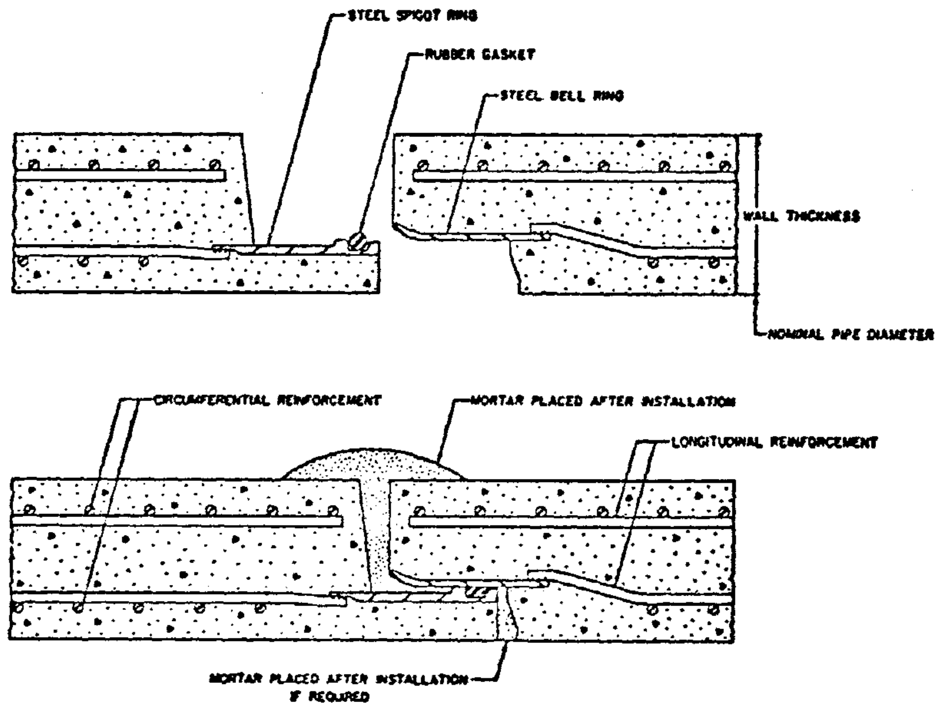
Fig. 5. Noncylinder Nonprestressed Concrete Pipe and Joint – R C

The pipe shown has two reinforcing cages, although the number of cages may vary. The joint may also be formed by a concrete bell and spigot, but the use of steel is more common.

Noncylinder Concrete Pipe, Prestressed – P C

Prestressed concrete pressure pipe was first produced commercially in France in 1937. Since that time, this pipe has been manufactured and used with varying degrees of success in a number of places outside the United States. Only a small number of installations of prestressed noncylinder pipe have been made in the United States, including installations made in 1941 and 1943 at Chicago. But some manufacturers in this country have spent much time and effort in research toward development of an acceptable noncylinder prestressed pipe that can be manufactured economically.

RC-REINFORCED CONCRETE PRESSURE PIPE



JOINT DETAILS

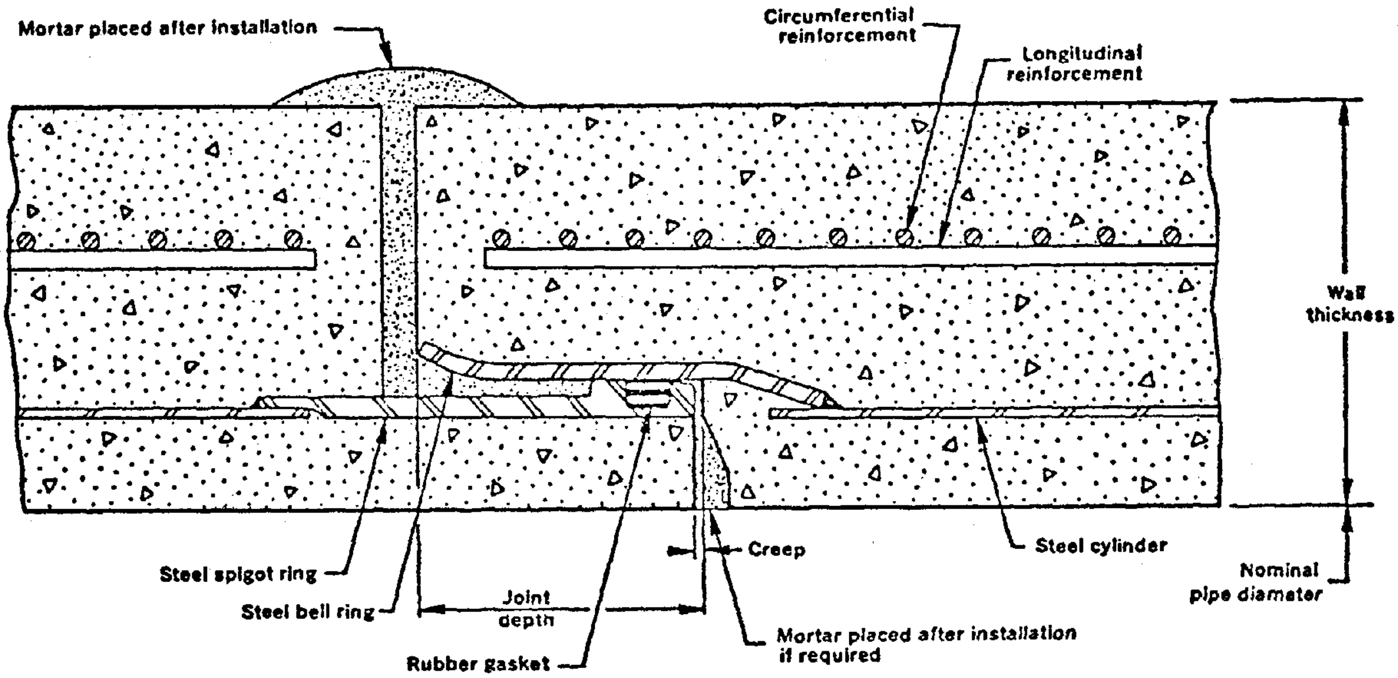
FIG. 6

NOMINAL INSIDE DIAMETER	NOMINAL WALL THICKNESS	NOMINAL STANDARD LENGTH	NORMAL MAXIMUM OPERATING HEAD	WEIGHT PER FOOT
24"	3-1/2"	16'	60'	340 lbs.
30"	3-1/2"	16'	60'	420 lbs.
36"	4"	16'	65'	565 lbs.
42"	4-1/2"	16'	70'	730 lbs.
48"	5"	16'	75'	920 lbs.
54"	5-1/2"	16'	85'	1130 lbs.
60"	6"	16'	90'	1360 lbs.
66"	6-1/2"	16'	95'	1615 lbs.
78"	7-1/2"	16'	110'	2180 lbs.
84"	8"	16'	115'	2500 lbs.
90"	8-3/4"	16'	115'	3020 lbs.
96"	9"	16'	120'	3200 lbs.
102"	9-1/2"	16'	120'	3585 lbs.
108"	10"	16'	120'	3960 lbs.
120"	10"	16'	120'	4385 lbs.
126"	10-1/2"	16'	120'	4830 lbs.
132"	11"	16'	120'	5300 lbs.
144"	12"	16'	120'	6300 lbs.
156"	13"	10'	120'	7420 lbs.

TABLE FOR GENERAL AVAILABILITY OF PIPE PARAMETERS

TABLE I (From Ref. 2)

RCC- REINFORCED CONCRETE CYLINDER PIPE



JOINT DETAIL

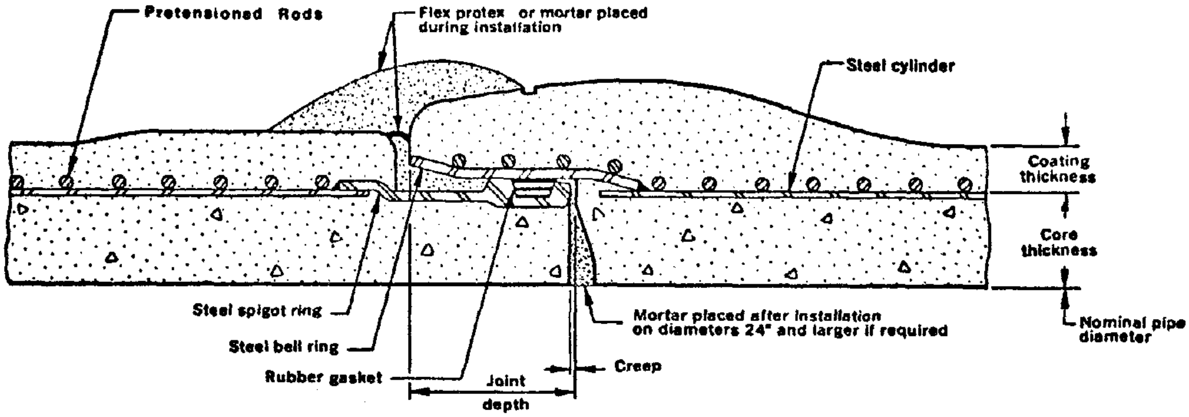
FIG. 7

AWWA C300 PIPE REQUIREMENTS AND WEIGHTS FOR RCC PIPE

PIPE ID (in.)	MINIMUM THICKNESS		WEIGHT PER FOOT
	TOTAL PIPE WALL (in.)	CONCRETE LINING (in.)	
24	3½	1	349
30	3½	1	421
36	4	1	567
42	4½	1	734
48	5	1¼	931
54	5½	1¼	1141
60	6	1¼	1373
66	6½	1½	1637
72	7	1½	1912
78	7½	1½	2208
84	8	1½	2526
90	8	1¾	2699
96	8½	1¾	3048

TABLE II (From Ref. 1, Part III)

RCCP- REINFORCED CONCRETE CYLINDER PRETENSIONED PIPE



JOINT DETAIL

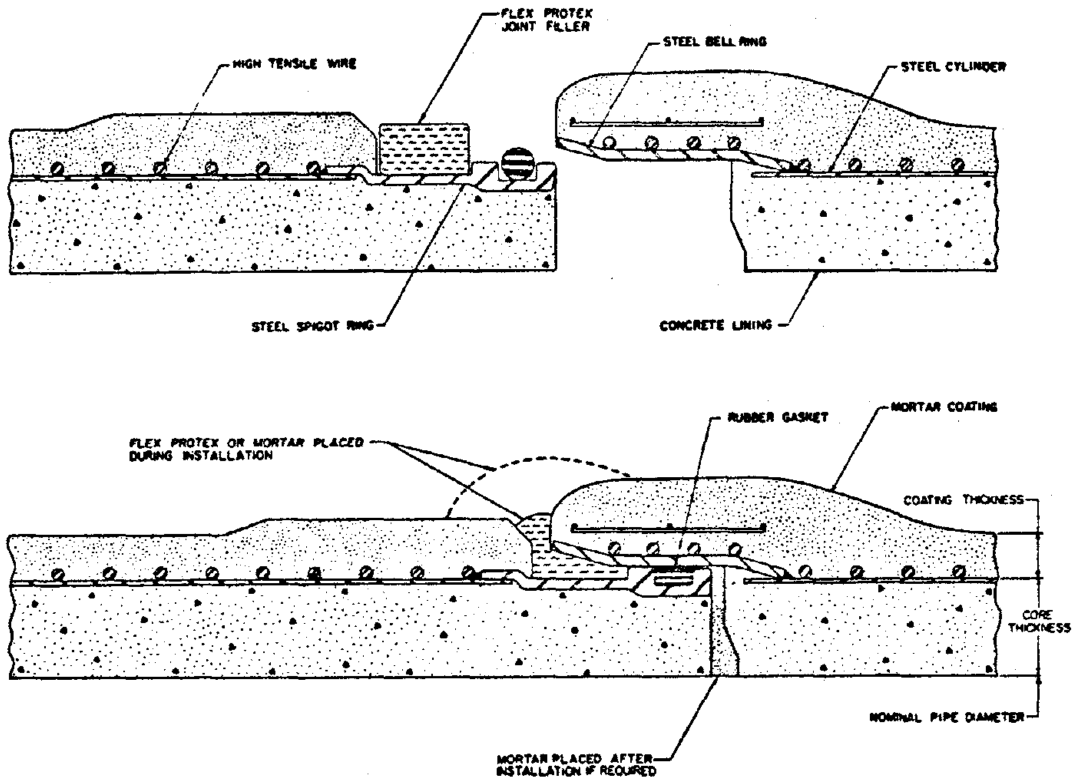
FIG. 8

TYPICAL DESIGNS (fs = 16,500 psi) FOR RCCP PIPES

Pipe Inside Diameter (Inches)	12	14	16	18	20	21	24	27	30	33	36	39	42
Cylinder Outside Dia. (inches)	13 3/8	15¼	17 3/8	19¾	21¾	22¾	25¾	28¾	31 7/8	34 7/8	37 7/8	40 7/8	43 7/8
100 psi													
A_T (Inches^2/Foot)	0.99	0.99	0.99	1.07	1.07	1.07	1.14	1.17	1.20	1.24	1.44	1.48	1.69
Cylinder t (Inches)	0.060	0.060	0.060	0.067	0.067	0.067	0.075	0.075	0.075	0.075	0.090	0.090	0.106
Wire or Bar Diameter (Inches)	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.250	0.250	0.250
Bell t (Inches)	0.132	0.132	0.132	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190
Pipe Weight (Pound/Foot)	85	90	105	135	150	155	175	200	225	245	270	300	320
150 psi	12	14	16	18	20	21	24	27	30	33	36	39	42
A_T (Inches^2/Foot)	0.99	0.99	0.99	1.07	1.18	1.24	1.39	1.56	1.73	1.89	2.05	2.22	2.38
Cylinder t (Inches)	0.060	0.060	0.060	0.067	0.067	0.067	0.075	0.075	0.106	0.106	0.106	0.106	0.140
Wire or Bar Diameter (Inches)	0.207	0.207	0.207	0.207	0.207	0.250	0.250	0.313	0.250	0.313	0.375	0.375	0.375
Bell t (Inches)	0.132	0.132	0.132	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190
Pipe Weight (Pound/Foot)	85	90	105	135	150	160	180	210	240	265	295	325	350
200 psi	12	14	16	18	20	21	24	27	30	33	36	39	42
A_T (Inches^2/Foot)	0.99	1.10	1.26	1.43	1.57	1.65	1.86	2.08	2.30	2.52	2.74	2.96	3.17
Cylinder t (Inches)	0.060	0.060	0.060	0.067	0.075	0.075	0.106	0.106	0.106	0.140	0.140	0.140	0.170
Wire or Bar Diameter (Inches)	0.207	0.207	0.250	0.313	0.313	0.313	0.313	0.375	0.375	0.375	0.438	0.438	0.438
Bell t (Inches)	0.132	0.132	0.132	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.190
Pipe Weight (Pound/Foot)	85	95	110	140	160	170	190	225	260	290	320	350	380
250 psi	12	14	16	18	20	21	24	27	30	33	36	39	42
A_T (Inches^2/Foot)	1.21	1.38	1.57	1.78	1.96	2.05	2.32	2.59	2.88	3.14	3.41	3.68	3.96
Cylinder t (Inches)	0.060	0.067	0.075	0.106	0.106	0.106	0.140	0.140	0.140	0.170	0.170	0.180	0.180
Wire or Bar Diameter (Inches)	0.250	0.313	0.313	0.313	0.313	0.375	0.313	0.375	0.438	0.438	0.500	0.500	0.500
Bell t (Inches)	0.132	0.132	0.132	0.190	0.190	0.190	0.190	0.190	0.190	0.190	0.250	0.250	0.250
Pipe Weight (Pound/Foot)	90	100	120	150	165	180	205	240	280	315	350	380	415
300 psi	12	14	16	18	20	21	24	27	30	33	36	39	42
A_T (Inches^2/Foot)	1.45	1.65	1.87	2.14	2.35	2.46	2.78	3.11	3.44	3.77	4.09	4.42	4.75
Cylinder t (Inches)	0.067	0.075	0.106	0.106	0.140	0.140	0.140	0.170	0.170	0.180	0.212	0.212	0.212
Wire or Bar Diameter (Inches)	0.313	0.313	0.313	0.375	0.375	0.375	0.438	0.438	0.500	0.500	0.500	0.500	0.500
Bell t (Inches)	0.132	0.132	0.132	0.190	0.190	0.190	0.190	0.190	0.250	0.250	0.250	0.250	0.250
Pipe Weight (Pound/Foot)	95	105	125	155	175	190	215	255	295	340	380	410	440

TABLE III (From Ref. 6)

PCC - PRESTRESSED CONCRETE CYLINDER PIPE



JOINT DETAILS

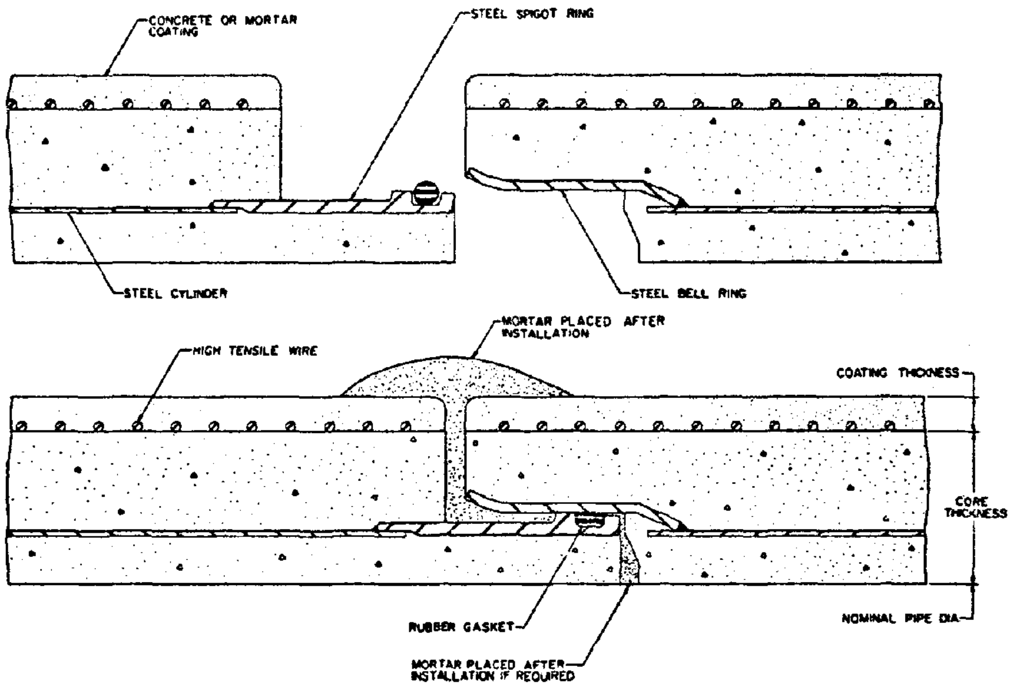
FIG. 9

Nominal Diameter inches	Core Thickness Including Cylinder inches	Minimum Mortar Coating Thickness inches	Nominal Length feet	Weight lbs./ft.
16	1	13/16	16 or 20	125
18	1-1/8	13/16	16 or 20	145
20	1-1/4	13/16	16 or 20	170
24	1-1/2	13/16	16 or 20	225
27	1-11/16	13/16	16 or 20	270
30	1-7/8	13/16	16 or 20	325
36	2-1/4	13/16	16 or 20	430
42	2-5/8	13/16	16 or 20	555
48	3	13/16	16 or 20	700
54	3-3/8	13/16	16 or 20	855
60	3-3/4	13/16	16 or 20	1,030
66	4-1/8	13/16	16 or 20	1,215
72	4-1/2	13/16	16 or 20	1,420

Available length is a function of individual plant capabilities.

TABLE IV (From Ref. 2)

PCEC- PRESTRESSED CONCRETE EMBEDDED CYLINDER PIPE



JOINT DETAILS

FIG. 10

Nominal Diameter inches	Nominal Length feet	Minimum Mortar Coating Thickness inches	Nominal Concrete Coating Thickness inches	Standard Cores			D/16 Cores	
				Core Thickness inches	Weight lbs/ft. With Mortar Coating	Weight lbs/ft. With Concrete Coating	Core Thickness inches	Weight lbs/ft. With Mortar Coating
24	16 or 20	13/16		2-1/4	300			
30	16 or 20	13/16		2-1/4	365			
36	16 or 20	13/16		2-1/4	430		2-1/4	430
42	16 or 20	13/16		2-5/8	555		2-5/8	555
48	16 or 20	13/16		3	700		3	700
54	16 or 20	13/16		4	985		3-3/8	855
60	16 or 20	13/16		4-1/2	1200		3-3/4	1030
66	16 or 20	13/16	1-1/2	5	1440	1615	4-1/8	1215
72	16 or 20	13/16	1-1/2	5-1/2	1700	1885	4-1/2	1420
78	16 or 20	13/16	1-1/2	6	1980	2180	4-7/8	1605
84	16 or 20	13/16	1-1/2	6-1/2	2275	2500	5-1/4	1870
90	16 or 20	13/16	1-1/2	6-1/2	2410	2660	5-5/8	2100
96	16 or 20	13/16	1-1/2	6-1/2	2570	2885	6	2390
102	16 or 20	13/16	1-1/2	6-1/2	2735	2990	6-3/8	2690
108	16 or 20	13/16	1-1/2	7	3080	3335	6-3/4	2960
114	16	13/16	1-1/2				7-1/8	3300
120	16	1	2	8	3935	4385	7-1/2	3705
126	16	1	2	8-1/2	4355	4830	7-7/8	4055
132	16	1	2				8-1/4	4420
138	16	1	2				8-5/8	4800
144	12	1	2		5750	6300	9	5200

Available lengths, coating type and core thickness are functions of individual plant capabilities.

TABLE V (From Ref. 2)

characteristics of the most commonly used 5 types of standard pipe described in II.1 - larger diameter pipe is made according to customer's specifications.

3. Usage conditions

Table I of WA Report IR-3 contains the basic-usage information data for all types of pipe, including reinforced concrete and prestressed concrete pipe. The data in this table cover: design pressures, diameters, lengths, thicknesses, joints, lining, material properties, laying conditions and design criteria.

The following Figs. 11, 12 and 13 illustrate in greater detail the bedding conditions for concrete pipes, in terms of pipe geometry, bedding materials and load factors. Tables VI and VII give the load factors L_f for circular pipes with positive projecting embankment. The bedding classes (A,B,C,D), and the parameters H, B_c and the projection ratio p in these tables are defined in Figs. 12 and 13, and r_{sd} is the settlement ratio:

$$r_{sd} = \frac{(S_m + S_g) - (S_f + d_c)}{S_m}$$

S_m = settlement of the adjacent soil of height p B_c,

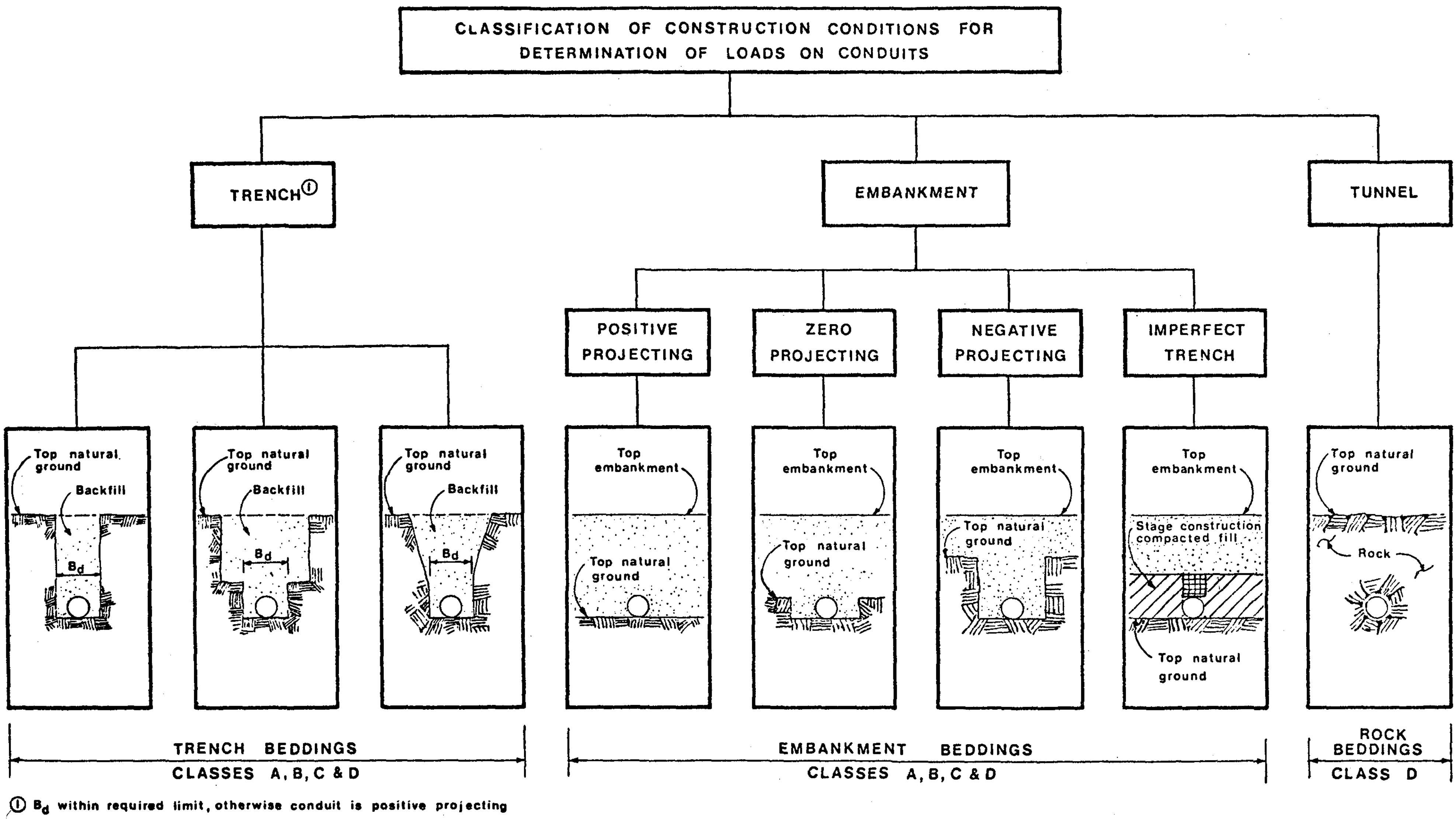
S_g = settlement of natural ground or compacted fill, surface adjacent to pipe,

S_f = settlement of the pipe into its bedding foundation,

d_c = deflection of the vertical height of pipe,

B_c = outside diameter of pipe,

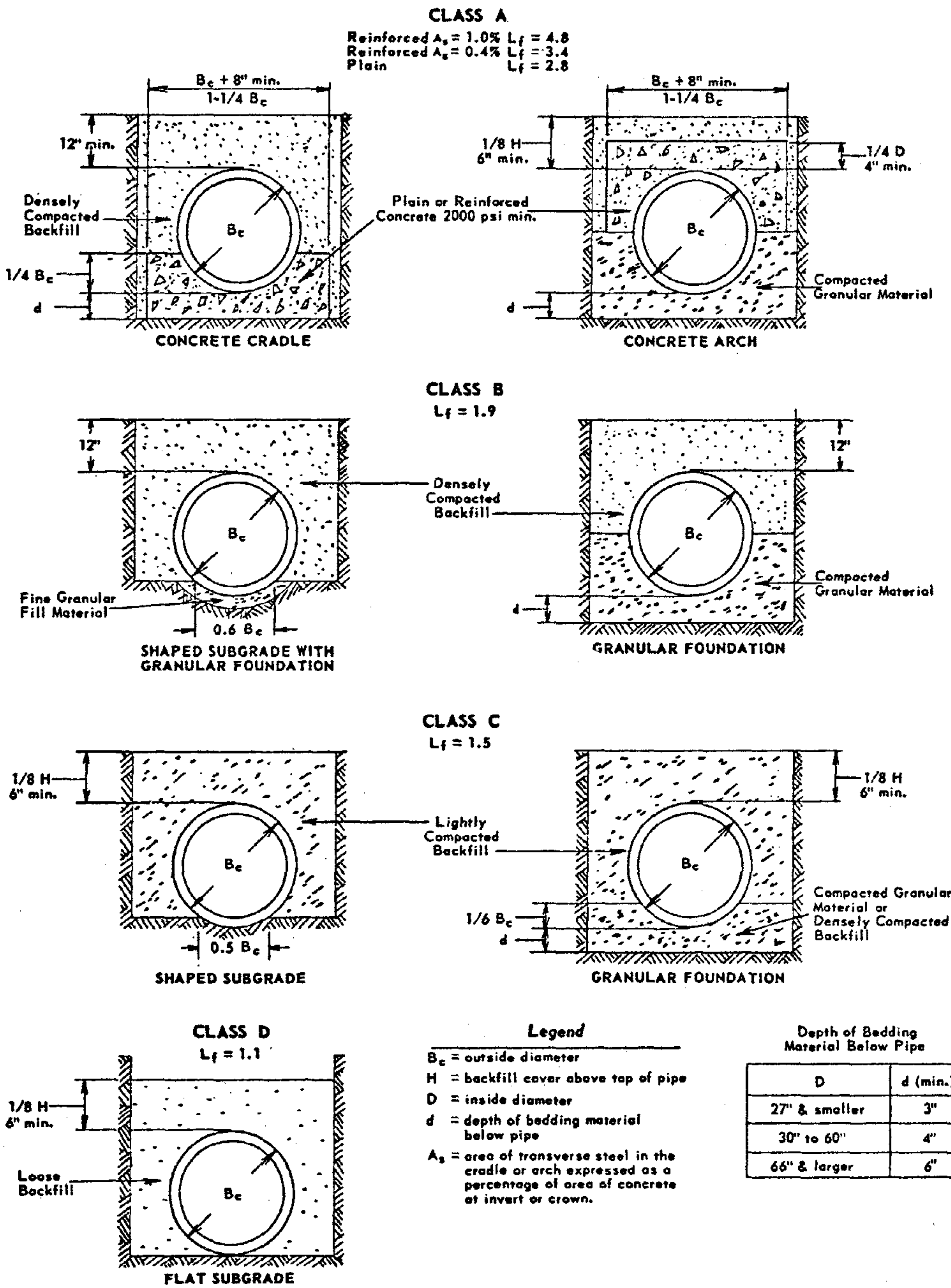
(see Ref. 1 Concrete Pipe Design Manual, American Concrete Pipe Association, Feb., 1974).



-14-

FIG. 11
(From Ref. 35, Part IV)

TRENCH BEDDINGS



Legend

- B_c = outside diameter
- H = backfill cover above top of pipe
- D = inside diameter
- d = depth of bedding material below pipe
- A_s = area of transverse steel in the cradle or arch expressed as a percentage of area of concrete at invert or crown.

Depth of Bedding Material Below Pipe

D	d (min.)
27" & smaller	3"
30" to 60"	4"
66" & larger	6"

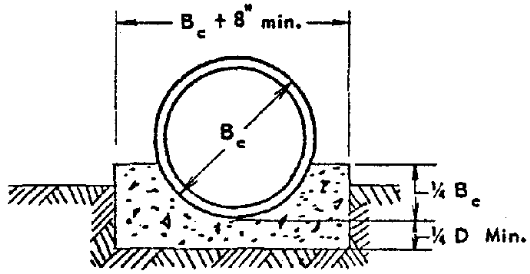
FIG. 12 (From Ref. 12)

EMBANKMENT BEDDINGS

(FOR LOAD FACTOR L_F SEE TABLES VI & VII)

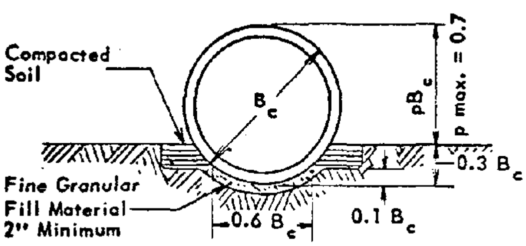
ROCK OR OTHER NONCOMPRESSIBLE FOUNDATION — Trench & Embankment beddings where ledge rock, rocky or gravelly soil, hard pan or other unyielding foundation material is encountered, the hard unyielding material shall be excavated below the elevation of the *concrete cradle* (Class A) *or the bottom of the pipe or* pipe bell (Class B & C Beddings) for a depth of at least 6 inches or ½ inch for each foot of fill over the top of the pipe, whichever is greater, but not more than ¾ the nominal diameter of the pipe. For Class D Bedding, the depth shall be 6 inches. The width of the excavation shall be one foot greater than the outside diameter of the pipe. The excavation shall be refilled with selected fine compressible material, such as silty clay or loam, lightly *compacted and* shaped *as* required *for* the specified class of bedding.

CLASS A

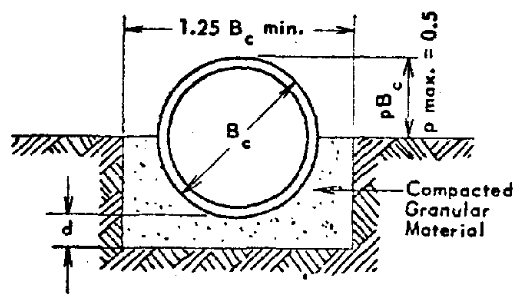


CONCRETE CRADLE

CLASS B

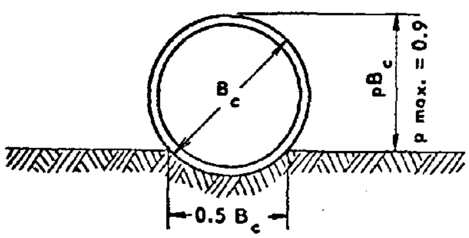


SHAPED SUBGRADE WITH GRANULAR FOUNDATION

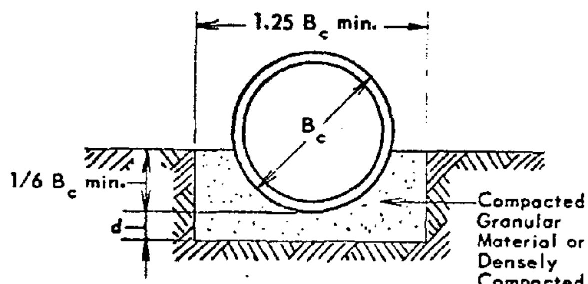


GRANULAR FOUNDATION

CLASS C

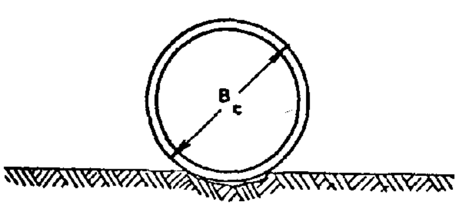


SHAPED SUBGRADE



GRANULAR FOUNDATION

CLASS D



FLAT SUBGRADE

Legend

B_c = outside diameter
H = fill cover above top of pipe
D = inside diameter
d = depth of bedding material below pipe

Depth of Bedding Material Below Pipe

D	d (min.)
27" & smaller	3"
30" to 60"	4"
66" & larger	6"

FIG 13 (From Ref. 12)

L_F – LOAD FACTORS FOR CIRCULAR PIPE POSITIVE PROJECTING EMBANKMENT INSTALLATIONS

$\frac{H}{B_c}$	CLASS A BEDDING					CLASS B BEDDING				
p = 0.9										
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	11.26	8.87	8.87	8.87	8.87	4.19	3.82	3.81	3.81	3.81
1.0	6.61	5.37	5.37	5.37	5.37	3.34	3.00	3.00	3.00	3.00
1.5	5.81	4.83	4.47	4.47	4.47	3.13	2.83	2.71	2.71	2.71
2.0	5.48	4.49	4.35	4.19	4.19	3.03	2.77	2.67	2.61	2.61
3.0	5.18	4.50	4.21	4.06	3.88	2.94	2.72	2.62	2.56	2.50
5.0	4.97	4.37	4.11	3.97	3.81	2.88	2.67	2.58	2.52	2.46
10.0	4.82	4.28	4.04	3.90	3.76	2.83	2.64	2.55	2.50	2.44
15.0	4.77	4.25	4.01	3.88	3.74	2.81	2.63	2.54	2.49	2.43
p = 0.7										
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	7.52	6.54	6.54	6.54	6.54	3.00	2.88	2.88	2.87	2.87
1.0	5.61	4.79	4.79	4.79	4.79	2.73	2.58	2.58	2.58	2.58
1.5	5.17	4.46	4.19	4.19	4.19	2.65	2.50	2.44	2.44	2.44
2.0	4.98	4.35	4.11	3.99	3.98	2.61	2.48	2.42	2.39	2.39
3.0	4.80	4.25	4.02	3.90	3.75	2.58	2.45	2.40	2.36	2.32
5.0	4.66	4.18	3.95	3.84	3.70	2.55	2.43	2.38	2.35	2.31
10.0	4.57	4.12	3.91	3.79	3.66	2.53	2.42	2.36	2.33	2.30
15.0	4.53	4.09	3.89	3.77	3.65	2.52	2.41	2.36	2.33	2.29
p = 0.5										
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	4.84	4.54	4.55	4.55	4.55	2.37	2.33	2.33	2.33	2.33
1.0	4.33	3.97	3.97	3.97	3.97	2.31	2.25	2.25	2.25	2.25
1.5	4.18	3.83	3.68	3.68	3.68	2.28	2.23	2.20	2.20	2.20
2.0	4.11	3.79	3.65	3.58	3.58	2.27	2.22	2.20	2.19	2.18
3.0	4.04	3.75	3.62	3.54	3.45	2.26	2.22	2.19	2.18	2.16
5.0	3.99	3.72	3.58	3.51	3.43	2.26	2.21	2.19	2.17	2.16
10.0	3.95	3.69	3.56	3.49	3.41	2.25	2.20	2.18	2.17	2.15
15.0	3.94	3.68	3.56	3.48	3.40	2.25	2.20	2.18	2.17	2.15
p = 0.3										
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	3.49	3.41	3.41	3.41	3.41	2.11	2.10	2.10	2.10	2.10
1.0	3.40	3.28	3.28	3.28	3.28	2.10	2.08	2.08	2.08	2.08
1.5	3.37	3.25	3.20	3.20	3.20	2.09	2.08	2.07	2.07	2.07
2.0	3.35	3.24	3.20	3.16	3.16	2.09	2.08	2.07	2.07	2.07
3.0	3.34	3.23	3.18	3.15	3.11	2.09	2.08	2.07	2.07	2.06
5.0	3.33	3.22	3.17	3.14	3.11	2.09	2.08	2.07	2.07	2.06
10.0	3.32	3.22	3.17	3.14	3.10	2.09	2.08	2.07	2.07	2.06
15.0	3.32	3.22	3.17	3.14	3.10	2.09	2.08	2.07	2.07	2.06
ZERO PROJECTING										
	2.83					2.02				

TABLE VI (From Ref. 1)

L_F — LOAD FACTORS FOR CIRCULAR PIPE
POSITIVE PROJECTING EMBANKMENT INSTALLATIONS

$\frac{H}{B_c}$	CLASS C BEDDING					CLASS D BEDDING				
	p = 0.9									
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	3.01	2.82	2.82	2.82	2.82	1.51	1.46	1.46	1.46	1.46
1.0	2.55	2.35	2.35	2.35	2.35	1.39	1.33	1.33	1.33	1.33
1.5	2.42	2.26	2.16	2.16	2.16	1.35	1.29	1.27	1.27	1.27
2.0	2.37	2.20	2.14	2.10	2.10	1.33	1.28	1.26	1.24	1.24
3.0	2.31	2.17	2.10	2.07	2.02	1.31	1.27	1.24	1.23	1.22
5.0	2.27	2.14	2.08	2.04	2.00	1.30	1.26	1.24	1.22	1.21
10.0	2.24	2.12	2.06	2.03	1.99	1.29	1.25	1.23	1.22	1.20
15.0	2.23	2.10	2.05	2.02	1.98	1.29	1.25	1.23	1.21	1.20
	p = 0.7									
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	2.35	2.27	2.27	2.27	2.27	1.33	1.30	1.30	1.30	1.30
1.0	2.18	2.08	2.08	2.08	2.08	1.27	1.24	1.24	1.24	1.24
1.5	2.13	2.03	1.99	1.99	1.99	1.25	1.22	1.20	1.20	1.20
2.0	2.10	2.01	1.97	1.95	1.95	1.24	1.21	1.20	1.19	1.19
3.0	2.08	2.00	1.96	1.94	1.91	1.24	1.21	1.19	1.18	1.17
5.0	2.06	1.98	1.95	1.93	1.90	1.23	1.20	1.19	1.18	1.17
10.0	2.05	1.98	1.94	1.92	1.89	1.22	1.20	1.18	1.18	1.17
15.0	2.04	1.97	1.94	1.91	1.89	1.22	1.20	1.18	1.18	1.17
	p = 0.5									
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	1.94	1.92	1.92	1.92	1.92	1.19	1.18	1.18	1.18	1.18
1.0	1.90	1.86	1.86	1.86	1.86	1.17	1.16	1.16	1.16	1.16
1.5	1.88	1.85	1.83	1.83	1.83	1.16	1.15	1.14	1.14	1.14
2.0	1.88	1.84	1.83	1.82	1.82	1.16	1.15	1.14	1.14	1.14
3.0	1.87	1.84	1.82	1.81	1.80	1.16	1.15	1.14	1.14	1.13
5.0	1.86	1.83	1.82	1.81	1.80	1.16	1.14	1.14	1.13	1.13
10.0	1.86	1.83	1.81	1.80	1.79	1.15	1.14	1.14	1.13	1.13
15.0	1.86	1.83	1.81	1.80	1.79	1.15	1.14	1.14	1.13	1.13
	p = 0.3									
	$r_{sd}p = 0$	0.1	0.3	0.5	1.0	$r_{sd}p = 0$	0.1	0.3	0.5	1.0
0.5	1.76	1.76	1.76	1.76	1.76	1.12	1.11	1.11	1.11	1.11
1.0	1.76	1.75	1.75	1.75	1.75	1.11	1.11	1.11	1.11	1.11
1.5	1.75	1.74	1.74	1.74	1.74	1.11	1.11	1.11	1.11	1.11
2.0	1.75	1.74	1.74	1.74	1.74	1.11	1.11	1.11	1.11	1.11
3.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.11	1.10
5.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.11	1.10
10.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.10	1.10
15.0	1.75	1.74	1.74	1.73	1.73	1.11	1.11	1.11	1.10	1.10
	ZERO PROJECTING									
	1.70					1.10				

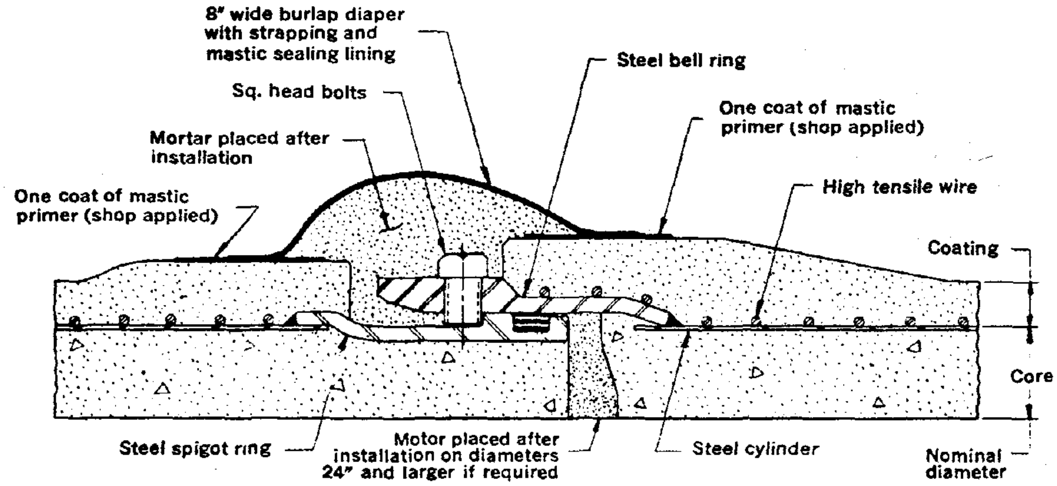
TABLE VII (From Ref. 1)

4. Special elements

All fittings for closures, curves, bends, branches, manholes, outlets, connections for main valves and other pipeline appurtenances are custom made out of steel and cement-mortar lined and coated. The design of such special elements is based on test data and empirical formulas, and subjected to the manufacturing limitations of section II.6 and the specifications of Part III. Details and examples of one of the commonly used Bell-Bolt Tied Joint used with a variety of these fittings is shown in Fig. 13A.

5. Joints

All joints of concrete pipelines are of the bell-and-spigot type, most with flared bells (Fig. 14) and some with flush bells (Fig. 15). The bell ring and the spigot ring are made out of steel and welded to the inner steel cylinder or to the reinforcing bar cage of the pipe. The spigot ring has an outer rectangular groove into which is stretched a rubber gasket of circular cross-section. When the bell ring is pushed over the spigot ring, it compresses the gasket into the groove, thus sealing the joint. When on site the originally round rubber gasket occupies almost the entire rectangular cross-section groove as shown in Fig. 16. The joint gap is grouted on site with cement mortar. The gasketed joint, while sealing the connection between two pipe segments, allows the small joint departures needed by minor changes in level and in direction of the pipeline. Table VIII and Fig. 17 give the maximum joint opening recommended for layout purposes and the maximum additional watertight extensibility for high pressure service, which determines the maximum joint rotation before leakage (see VI.2).

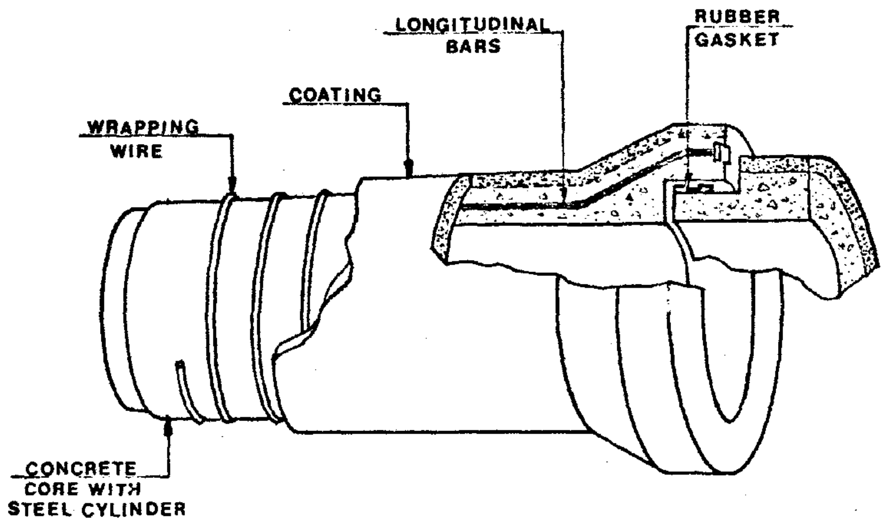


TYPICAL DETAIL OF BELL - BOLT FLEXIBLE TIED JOINT

FIG. 13A

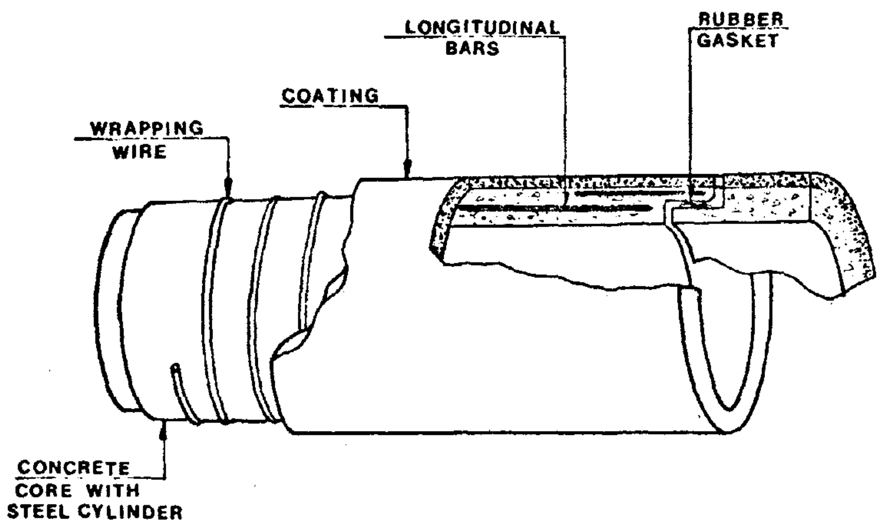
A large variety of specials and fittings is available for use with Lock Joint Pipe. Bends, tees, wyes and the like are all fully engineered, meticulously manufactured and are accurate in laying lengths. Pipe branches and outlets may be designed for jointing with pipe and fittings of other materials.

The Bell-Bolt Flexible Tied Joint effectively resists unbalanced thrusts in a pipeline. This rubber and steel joint is secured by bolts set around the perimeter of the joint and tightened with a ratchet wrench. This joint eliminates the need for thrust blocks.



PRESTRESSED CONCRETE PIPE FLARED BELL TYPE JOINT

FIG. 14



PRESTRESSED CONCRETE PIPE FLUSH BELL TYPE JOINT

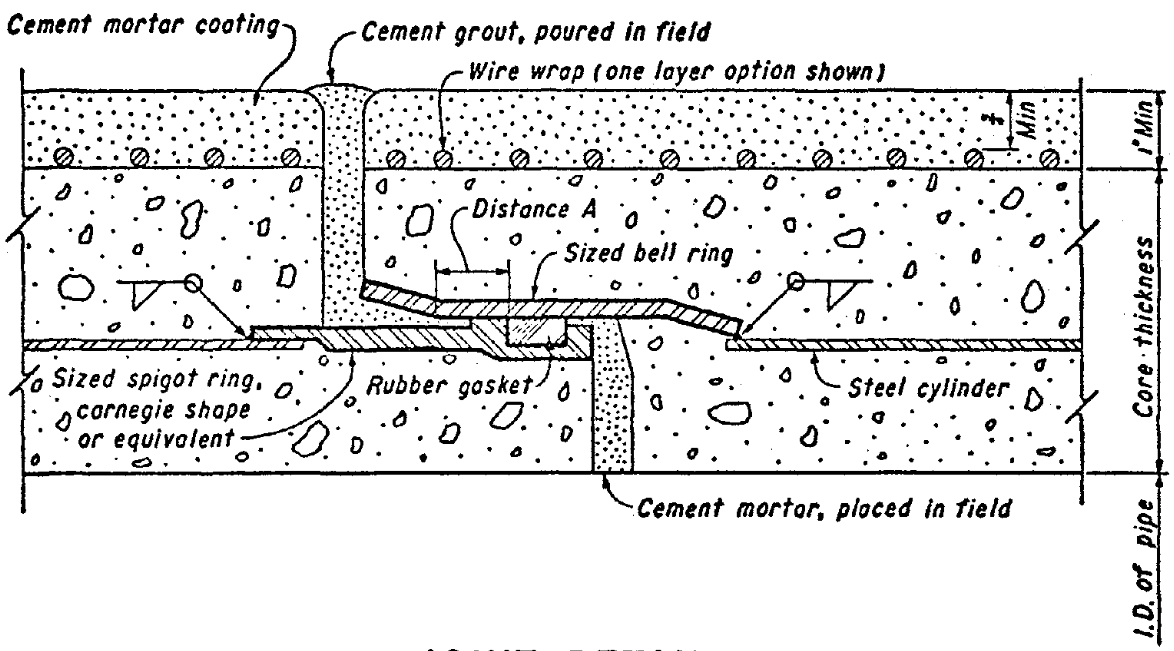
FIG. 15

6. Manufacturing techniques

Concrete pipes without a steel cylinder are manufactured vertically by setting the reinforcing-bar cage of longitudinal and circumferential bars, with the bell and spigot rings welded at their ends between external and internal cylindrical steel forms, and by pouring concrete between the forms. The concrete is vibrated by means of regular vibrators.

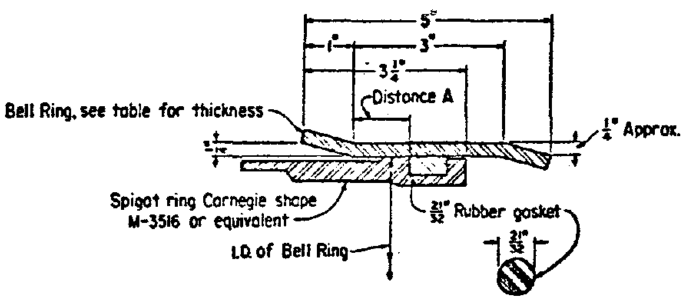
The hot-rolled steel cylinder, usually 16-18 gauge, is manufactured by welding along a 4-foot wide flat plate along a continuous spiral joint. The exclusive purpose of the cylinder is to guarantee the water tightness of the pipe under pressure. The bell and spigot rings are welded to the steel cylinder ends. In the manufacture of PCC pipe (Fig. 2) of relatively small distances, the steel cylinder is lined with concrete by rotating it around its horizontal axis so that the centrifugal force pushes the concrete against the internal cylinder wall. Because of the different density of the concrete components, stone is denser in the neighborhood of the internal cylinder-wall while sound and cement tend to accumulate towards the inner concrete-lining wall. Once the concrete of the lining is set, a spiral of high-strength steel wire, with an ultimate strength of up to 300,000 psi, is stretched while the pipe rotates over the external surface of the steel cylinder, at a tension and a pitch dictated by the maximum inner pressure in the pipe. The most commonly used wire diameter vary between No. 4 gauge (.225 in) and 15/16 in. and the spacing between wire loops varies between .19 in. and 1.5 in. The wires are pulled with a force producing tensile stresses of the order of 75% of their ultimate strength and are anchored to the bell and spigot rings of the pipe. The prestressed pipe is finally coated with cement mortar.

TYPICAL BELL AND SPIGOT DETAILS FOR PCC AND PCEC PIPES



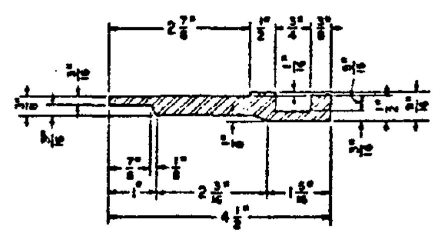
JOINT DETAIL

FIG. 16



BELL & SPIGOT RING ASSEMBLY DETAIL

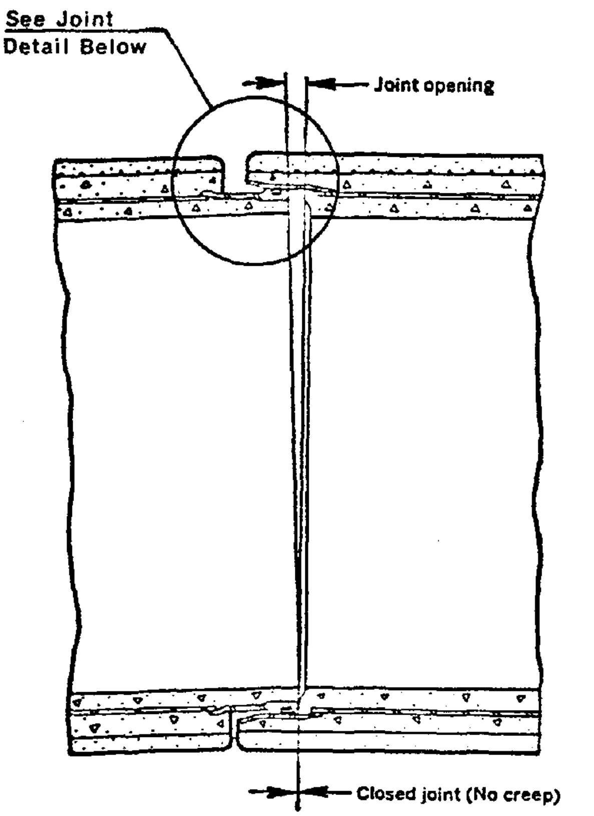
FIG. 16A



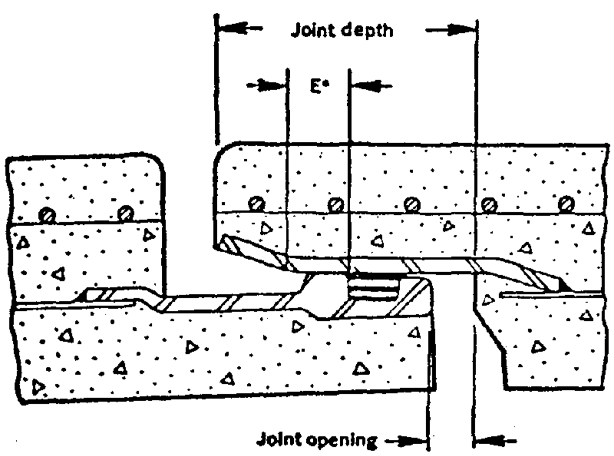
CARNEGIE SHAPE M-3516 SPIGOT

FIG. 16B

PERMISSIBLE JOINT OPENINGS AND MOVEMENT FOR PCC AND PCEC PIPES



TYPICAL SECTION THRU JOINT



JOINT DETAIL

All dimensions in inches

Type	Pipe Dia.	Joint Depth	Joint** Opening	E*
PCC	16-30	3¼	¾	⅜
PCC	36	3⅜	¾	½
PCC	42	3¾	⅞	¾
PCEC	42	4⅛	⅞	1⅛
PCC	48	3⅞	1	¾
PCEC	48	4⅛	1	1
	54	4⅛	1⅛	⅞
	60	4¼	1¼	⅞
	66	4⅜	1⅜	⅞
	72	4½	1½	⅞
	78	4⅝	1½	⅝
	84	4⅞	1½	⅞
	90	5	1½	1
	96	5⅛	1½	1⅛
	102	4⅞	1½	⅞
	108	6	1¾	1⅛
	114	6	1¾	1⅛
	120	6	1¾	1⅛
	126	6	1¾	1⅛
	132	6	1¾	1⅛
	138	6	1¾	1⅛
PCEC	144	6	1¾	1⅛

*E = Maximum additional watertight extensibility high pressure service
** = Maximum recommended for layout purposes

TABLE VIII

FIG. 17 (From Ref. 2)

In the manufacture of large diameter PCEC pipe (Fig. 3), the pipe is concreted vertically, by setting the steel cylinder between two steel forms and pouring and vibrating the concrete so as to both line and coat it with concrete. Once the concrete is set and steam cured, the prestressing wires are stretched along a spiral on the outer surface of the outer concrete coat and anchored to blocks welded to the end rings. The pipe is then finished by coating it with either a cement mortar or a fine aggregate concrete.

III. SPECIFICATIONS

The specifications for the manufacture of the 5 types of pipe described in Section II.1 are contained in AWWA Standards C-300, C-301, C-302 and C-303. The essential parts of these standards, as they apply to the 5 types of pipe, appear in Appendix A, together with the standards for the steel fittings, for three-edge-bearing tests and bell-and-spigot ring material properties. Essential design information from the AWWA Standards C-300, C-301, C-302, and C-303, and the BuRec Standard for RC pipes are reproduced in Appendix B.

PART III

APPENDIX "A"

Specifications

PART III. 1 RC

SPECIFICATIONS FOR REINFORCED CONCRETE PRESSURE PIPE WITH RUBBER AND STEEL JOINT

Produced According to
AWWA Standard C-302*

TYPE OF PIPE

The pipe shall be of the type known as Reinforced Concrete Pressure Pipe. It shall be reinforced with a cage or cages formed of circumferential and longitudinal steel. Steel joint rings shall be located at its ends and shall be securely anchored in the pipe. The steel structure shall be completely encased with dense concrete. Each pipe shall be constructed with a self-centering expansion joint sealed with a rubber gasket and capable of caring for normal movement due to earth settlement and extremes of temperature.

DIMENSIONS

The dimensions of the straight pipe shall be in accordance with the table on the facing page. Special pipes for bends, reducers, closure pieces and other fittings may be made in shorter lengths, as required.

The pipe shall be round and true. The average internal diameter of the straight pipe shall not be less than the nominal diameter by more than 1/4" for sizes 36" or smaller; by more than 3/8" for 42" and 48"; by more than 1/2" for 54" to 78"; nor by more than 3/4" for 84" or larger.

PIPE DESIGN

The circumfrential reinforcement shall consist of one or more cages whose configuration shall conform to the requirements shown in "Reinforced Concrete Pressure Pipe - Noncylinder Type, for Water and Other Liquids", AWWA Standard C-302. The cross-sectional area of the circumferential steel reinforcement to resist internal pressure only shall be no less than the maximum determined from equations (1) and (2).

$$A_s = \frac{6P_wD}{16{,}500-75P_w} \quad (1)$$

$$A_s = \frac{6\,(P_w+P_t)\,D}{16{,}500} \quad (2)$$

A_s = Cross-sectional area of circumferential steel reinforcement, sq. in. per ft. of pipe wall

P_w = Working pressure, psi

P_t = Transient pressure, psi

D = Inside diameter of pipe, inches

The pipe shall also be designed to resist the flexural and axial stresses produced by the combined effect of internal pressure and external load in the manner prescribed by AWWA C-302.

When the pipe is not designed for internal pressure, the reinforcement shall be in accordance with the appropriate class shown in "Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe," ASTM Designation C-76 or with 'Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe," ASTM Designation C-655.

Each pipe shall have a minimum longitudinal reinforcement equivalent to 1/2" round steel rods at a maximum of 42" center to center spacing with a minimum of six 1/2" round rods per pipe or equivalent. In pipe with two cages, the longitudinal steel shall be divided equally between the two cages, except that, when welded fabric is used, any extra longitudinals may all be placed in one cage.

PIPE JOINTS

The joint shall be sealed by a rubber gasket so that the joint will remain tight under all conditions of service, including movement due to expansion, contraction and normal settlement. Each length of pipe shall be provided with bell and spigot ends formed by steel rings securely fastened in the pipe wall. The spigot ring shall be lined with concrete on its interior surface, and the bell ring shall be covered with concrete on its exterior surface. Portions of the joint rings which will be exposed after the pipe is manufactured shall be protected from corrosion by an approved coating. The spigot ring shall have a groove for the purpose of receiving, holding and protecting the gasket. The joint surfaces shall be of such shape and dimensions that the joint will be self-centering when the pipes are laid so that the gasket will not be required to support the weight of the adjoining pipe.

Steel of flat section for bell rings 3/16" thick shall be used on pipe sizes up to and including 30" and shall conform to "Specifications for Hot-Rolled Carbon-Steel Sheets and Strip, Structural Quality", Grade C, ASTM Designation A-570.

Steel plate for bell rings 1/4" or more in thickness, and special shapes for spigot joint rings, shall conform to "Specification for Carbon Steel Bars Subject to Mechanical Property Requirements", Grade 50, ASTM Designation A-306.

The gasket sealing the joint shall be made of a special composition rubber having a texture to assure a watertight and permanent seal and shall be the product of a manufacturer having at least five years' experience in the manufacture of rubber gaskets for pipe joints. The gasket shall be a continuous ring, of suitable cross-section and of such size as to fill the groove on the spigot joint ring when the pipes are laid. The rubber gasket shall be the sole element depended upon to make the joint watertight and shall have smooth surfaces free from pitting, blisters, porosity and other imperfections. Cement mortar or other plastic materials used to finish the joint shall not be depended upon for watertightness.

Synthetic isoprene gaskets shall comply with the following physical requirements:

Tensile strength, min. psi	3000
Elongation at rupture, min. percent	425
Compression set, max. percent	20
Accelerated aging	
Tensile strength retained, min. percent of original	85
Elongation retained, min. percent of original	80
Water absorption	
Volume and weight increase, max. percent	5
Durometer hardness, points	60±5

The physical properties of the gaskets shall be determined in accordance with the following methods:

Tensile Strength	"Tension Testing of Vulcanized Rubber", ASTM Designation D-412
Elongation	"Tension Testing of Vulcanized Rubber", ASTM Designation D-412
Compression Set	"Compression Set of Vulcanized Rubber", ASTM Designation D-395, Method B, age 22 hours at 70°C
Accelerated Aging	"Oven Test for Aging of Rubber", ASTM Designation D-573, age 96 hours at 70°C
Water Absorption	"Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids", ASTM Designation D-471, age 48 hours at 70°C
Durometer Hardness	"Indentation Hardness of Rubber and Plastics by Means of a Durometer", Type A, ASTM Designation D-2240

STEEL REINFORCEMENT

The steel reinforcement shall be made of deformed bars or plain wire conforming to the requirements of "Specifications for Deformed Billet-Steel Bars for Concrete Reinforcement", Structural Grade, ASTM Designation A-615, "Specifications for Cold-Drawn Steel

Wire for Concrete Reinforcement", ASTM Designation A-82 or "Specifications for Welded Steel Wire Fabric for Concrete Reinforcement", ASTM Designation A-185.

CONCRETE

Cement shall fulfill the requirements of "Standard Specification for Portland Cement", ASTM Designation C-150. Concrete aggregates shall be composed of hard durable particles, clean and free from loam or organic materials. Water used in mixing the concrete shall be clean and free from deletrious amounts of acids, alkalis or organic materials.

The concrete used in the manufacture of the pipe shall consist of cement, sand and crushed stone or crushed or uncrushed gravel accurately proportioned for maximum density and specified strength. In no case shall the cement content be less than 564 lbs. (6 bags) per cubic yard in the finished product.

The concrete shall be placed in steel molds so constructed that the inner and outer forms, joint rings and reinforcement shall be held in circular and concentric positions. The molds shall be vibrated during the placing of each batch of concrete. Concrete may be placed by an alternate method provided, in conjunction with the curing procedure employed, it shall produce concrete of the required strength and quality.

The concrete shall have a minimum strength of 3000 psi at seven days and 4500 psi at 28 days as measured by 6" x 12" companion cylinders molded in accordance with the "Standard Method for Making and Curing Concrete Compression and Flexure Test Specimens in the Field", ASTM Designation C-31, and cured in the same manner and for the same duration as the pipe. To conform to the requirements of this section, the average of any ten consecutive strength tests of cylinders representing each type of concrete shall be equal to or greater than the specified strength and not more than 20% of the strength tests shall have values less than the specified strength.

CURING OF CONCRETE

Curing shall be by either steam or water. The use of water shall be limited to times when the temperature in the curing enclosure is continuously above 40°F. Adequate facilities and space shall be provided for proper curing. When the concrete in the pipe has attained a strength of 3,000 psi, the pipe may be delivered.

Steam Curing - The pipes shall be placed in the steam curing chamber or otherwise covered by a suitable enclosure that will allow proper circulation of steam. A delay period of from 1 to 4 hours shall be allowed before moist steam is admitted in contact with the pipes. The temperature within the enclosure shall be gradually raised to at least 110°F and not more than 150°F for a period of at least 24 hours. The preset time shall be included in the 24 hour period. Curing by steam shall be continuous, except during a period sufficient to remove the forms or supporting rings. The forms shall not be removed until at least 6 hours after the beginning of steam curing. Following this minimum period, in lieu of further steam curing, the pipes may be "tipped" from their bases and removed to the storage yard, where they shall be kept continuously moist by intermittent spraying for a period of at least 5 days.

Water Curing - The pipe shall be kept moist by water spraying for a period of 32 hours. The forms shall not be removed from the pipe until at least 12 hours after beginning of curing. After being placed in the storage yard, the pipe shall be kept moist by intermittent sprinkling for a further period of three days.

CURVES AND FITTINGS

Curves of long radius may be formed by the deflection of each joint, by the use of pipe on which the spigot joint rings are placed on a bevel or by bevel adapters. Fittings shall be designed to provide the same strength as the adjacent pipes. Elbows, tees, reducers and wyes shall be of steel cylinder type construction. Branch connections or openings such as manholes, air valves and blowoffs may be incorporated in straight pipe and shall be suitably reinforced. Fittings shall be provided with joint rings corresponding to those on adjoining straight pipes. Special adapters shall be provided where required to connect to valves or pipes of other manufacturers.

NOTE—Pipe lines utilizing the type of pipe covered by the above specifications, and with outlets and connections at structures utilizing joints of comparable quality, are designed to meet the following tests:

Infiltration...75 gallons per inch of diameter per mile of pipe per 24 hours

Exfiltration...125 gallons per inch of diameter per mile of pipe per 24 hours

Small cracks in the concrete which are not damaging should not be considered as cause for rejection.

The term "ASTM" shall mean the American Society for Testing Materials. The term "AWWA" shall mean the American Water Works Association. When specific specifications are cited, the designation shall be construed to refer to the latest revision.

*At the time of publication of this specification A.W.W.A. Committee 8320D had approved several changes, in "AWWA Standard for Reinforced - Concrete Water Pipe - Noncylinder Type, not Prestressed" designation C-302-64, which have been incorporated in the text.

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NOT REPRODUCIBLE

Sec. 2.1—Cement

2.1.1 *Type.* Cement for concrete work shall conform to the "Specifications for Portland Cement" (ASTM Designation C150). Either Type I or Type II may be used unless the purchaser specifies a particular type. Sampling and testing shall conform to the individual ATSM specification designated therein.

2.1.2 *Inspection.* Satisfactory facilities shall be provided for identifying, inspecting, and sampling cement at the mill, the warehouse, and the site of the work. The purchaser shall have the right to inspect the cement and obtain samples for testing at any of these points.

2.1.3 *Storage.* Cement shall be stored in a weathertight, dry, well-ventilated structure.

2.1.4 *Unusable.* Cement salvaged by cleaning cement sacks, mechanically or otherwise, shall not be used in the work. Cement containing lumps shall be rejected and shall be immediately removed from the site of the work.

2.1.5 *Temperature.* If the temperature of the cement exceeds 150F, it shall be stored until cooled to that temperature.

Sec. 2.2—Fine Aggregate

2.2.1 *General.* Fine aggregate for concrete and mortar shall consist of clean, hard, durable, uncoated particles of natural sand or of sand prepared from the product obtained by crushing stone or gravel. At the time of use the fine aggregate shall be entirely free of frozen material.

2.2.2 *Gradation.* Fine aggregate shall be well graded from coarse to fine and, when tested by means of laboratory sieves in accordance with the "Method of Test for Sieve or Screen Analysis of Fine and Coarse Aggregates" (ASTM Designation C136), shall conform to the gradation requirements in Table 1.

The gradation requirements given in Table 1 represent the extreme limits for determining the suitability of fine aggregate under this standard. To maintain uniformity of gradation for aggregate from any given source, a fineness modulus determination shall be made upon representative samples from that source. Thereafter the fineness modulus of all shipments therefrom shall not vary by more than ±0.20 from the fineness modulus of the representative sample, unless suitable, approved mix adjustments are made.

2.2.3 *Impurities.* Fine aggregate shall be free from injurious amounts of organic impurities and shall conform to Sec. 4.2 of "Specifications for Concrete Aggregates" (ASTM Designation C33-71a).

Sec. 2.3—Coarse Aggregate

2.3.1 *General.* Coarse aggregate for concrete shall consist either of hard, durable particles of crushed stone or of crushed or uncrushed gravel that conforms to the requirements and tests given in Sec. 2.3.2 and 2.3.3.

2.3.2 *Gradation.* Coarse aggregate shall be well graded from coarse to fine. The maximum size and gradation shall be subject to the approval of the purchaser and shall be such that the concrete can be readily placed in the mold, by the particular method used in placing it, to provide a solid, compact, homogeneous wall with a smooth surface. Tests for gradation of coarse aggregate shall be in accordance with the "Method of Test for Sieve or Screen Analysis of Fine and Coarse Aggregates" (ASTM Designation C136). Thin and elongated pieces, the maximum dimension of which exceeds five times the minimum, shall not be

TABLE 1

Gradation Requirements for Fine Aggregate

Sieve Size	Total Passing, by Weight, %
⅜ In.	100
No. 4	9[illegible]–100
No. 8	6[illegible]– 9[illegible]
No. 16	4[illegible]– 80
No. 30	2[illegible]– 70
No. 50	[illegible]– 50
No. [illegible]	– 10

TABLE 2

Permissible Amounts of Deleterious Substances in Coarse Aggregate

Material	Maximum Weight Limit, %
Soft particles	5.00
Coal and lignite	0.50
Clay lumps	0.25
Material finer than 200 sieve	1.00
Combined total of above items	5.00

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in excess of 10 per cent of the coarse aggregate by weight.

2.3.3 *Impurities.* Deleterious substances in coarse aggregate shall not exceed the amounts given in Table 2, as determined by sampling and testing procedures listed in the "Specifications for Concrete Aggregates" (ASTM Designation C33).

Sec. 2.4—Samples of Aggregates

At least four weeks prior to mixing concrete, the manufacturer, if required, shall provide, in suitable containers, samples of not less than 1 cu ft each of fine aggregate and coarse aggregate for preliminary approval. All samples shall be plainly labeled to indicate the source of the material, the date, and the name of the collector. Methods of sampling aggregates shall be in accordance with the "Methods of Sampling Aggregates" (ASTM Designation D75).

Sec. 2.5—Water

Water used for concrete and for curing pipe shall be fresh water and shall be clean and free from oil, acid, strong alkalies, or vegetable matter.

Sec. 2.6—Admixtures

At the option of the manufacturer, the concrete may contain a water-reducing, set-controlling admixture conforming to the "Specification for Chemical Admixtures for Concrete" (ASTM Designation C494). No admixture shall contain calcium chloride. The type and amount of admixture shall be subject to the approval of the purchaser.

Sec. 2.7—Steel for Cylinders and Fittings

2.7.1 *Steel sheets.* Steel sheets for pipe cylinders and fittings may be in cut lengths or coils and shall meet the requirements of the "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality" (ASTM Designation A570), Grade B or C, or "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Commercial Quality" (ASTM Designation A569), except that for steel covered by ASTM A569, the maximum carbon content shall be 0.25 per cent and the minimum yield shall be 27,000 psi.

2.7.2 *Steel plates.* Steel plates for pipe cylinders and fittings shall conform to the "Specifications for Low and Intermediate Tensile Strength Carbon Steel Plates for Structural Quality" (ASTM Designation A283), Grade B or C.

Sec. 2.8—Steel for Bar, Wire, and Wire Fabric Reinforcement

2.8.1 *Bars.* Steel bar reinforcement for concrete pipe or fittings shall be plain or deformed and shall conform to "Specifications for Carbon Steel Bars Subject to Mechanical Property Requirements" (ASTM Designation A306), Grade 80, or to "Specifications for Deformed Billet-Steel Bars for Concrete Reinforcement" (ASTM Designation A615–68), Grade 40, except that for plain bars supplied under ASTM A615–68, (1) the requirements of Sections 6, 7, and 14.3 shall not apply, (2) intermediate bar diameters shall meet the requirements of the next smaller bar number designation, and (3) bar diameters less than No. 3 shall meet the requirements for No. 3 bar.

2.8.2 *Wire.* Steel wire for reinforcement of concrete pipe shall conform to the "Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement" (ASTM Designation A82) or to the "Specifications for Deformed Steel Wire for Concrete Reinforcement" (ASTM Designation A496). Wire used for ties may be annealed.

2.8.3 *Wire fabric.* Wire fabric reinforcement for concrete pipe or for mortar coating for fittings shall conform either to the "Specifications for Welded Steel Wire Fabric for Concrete Reinforcement" (ASTM Designation A185) or to the "Specification for Welded Deformed Steel Wire Fabric for Concrete Reinforcement" (ASTM Designation A497).

Sec. 2.9—Steel for Joint Rings

Steel for bell rings less than ¼ in. thick shall conform to "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality" (ASTM Designation A570), Grade A, or to "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Commercial Quality" (ASTM Designation A569). Special shapes for spigot joint rings and steel for bell rings ¼ in. or more in thickness shall conform to "Specifications for Carbon Steel Bars Subject to Mechanical Property Requirements" (ASTM Designation A306), Grade 50, or to "Specifications for Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality" (ASTM Designation A283), Grade A, or to "Specifications for Merchant Quality Hot-Rolled Carbon Steel Bars" (ASTM Designation A575), Grade 1012, or to "Specifications for Special Quality Hot-Rolled Carbon Steel Bars" (ASTM Designation A576), Grade 1012, or to "Specifications for Steel Sheet and Strip, Carbon, Hot-Rolled Commercial Quality, Heavy-Thickness Coils (Formerly Plate)" (ASTM Designation A635).

Sec. 2.10—Steel Castings for Fittings

Steel castings for fittings shall conform to the "Specifications for Mild to Medium Strength Carbon Steel Castings for General Application" (ASTM Designation A27), Grade 70–36, normalized.

Sec. 2.11—Rubber for Gaskets

2.11.1 *General.* The gasket shall have smooth surfaces free from pitting, blisters, porosity, and other imperfections. The rubber compound shall contain not less than 50 per cent by volume of first-grade natural crude or first-grade synthetic rubber. The remainder of the compound shall consist of pulverized fillers free from rubber substitutes, reclaimed rubber, and deleterious substances. The compound shall meet the following physical requirements when tested in accordance with the indicated conditions and designated ASTM test methods.

2.11.2 *Tensile strength.* The tensile strength of the compound shall be at least 2,700 psi for natural rubber gaskets and 2,000 psi for synthetic rubber gaskets—"Method of Tension Testing of Vulcanized Rubber" (ASTM Designation D412).

2.11.3 *Elongation at rupture.* The elongation at rupture shall be at least 400 per cent for natural rubber gaskets and 350 per cent for synthetic rubber gaskets—"Method of Tension Testing of Vulcanized Rubber" (ASTM Designation D412).

2.11.4 *Specific gravity.* The specific gravity shall not vary by more than ±0.05 within the range of 0.95–1.45—"Methods for Chemical Analysis of Rubber Products" (ASTM Designation D297).

2.11.5 *Compression set.* The percentage of compression set shall not exceed 20. The compression set determination shall be made in accordance with "Methods of Test for Compression Set of Vulcanized Rubber" (ASTM Designation D395), Method B, with the exception that the disc shall be a ½-in.-thick section of the rubber gasket stock.

2.11.6 *Tensile strength after aging.* After being subjected to an accelerated aging test for 96 hr in air at 70C in accordance with "Method of Test for Accelerated Aging of Vulcanized Rubber by the Oven Method" (ASTM Designation D573) or in a pressure chamber for 48 hr at 70C in an oxygen atmosphere at 300 psi in accordance with "Method of Test for Accelerated Aging of Vulcanized Rubber by the Oxygen-Pressure Method" (ASTM Designation D572), the tensile strength of the compound shall be not less than 80 per cent of the tensile strength before aging.

2.11.7 *Shore durometer.* The Shore A durometer hardness shall be in the range of 50 to 65 and shall be determined in accordance with "Method of Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer" (ASTM Designation D2240–68), with the exception of Section 4 thereof. The determination shall be taken directly on the gasket.

2.11.8 *Test reports.* If required by the purchaser, the manufacturer shall submit test reports showing the physical properties of the rubber compound used in the manufacture of the gaskets.

Section 3—Design and Fabrication of Pipe

Sec. 3.1—General Requirements

3.1.1 *Laying lengths.* In general, pipe shall have a minimum nominal laying length of 8 ft, unless shorter lengths are required by weight or other considerations. The maximum lengths shall be as follows:

Internal Diameter *in.*	Maximum Laying Length *ft*
24 to 36 inclusive	20
39 and larger	24

3.1.2 *Diameter tolerances.* Pipe shall be round and true and shall have a smooth and dense interior surface. The mean internal diameter of any portion of each piece of pipe shall be not less than the design diameter or size specified by more than ¼ in. for 36-in. pipe, and smaller; by more than ⅜ in. for 42-in. and 48-in. pipe; by more than ½ in. for 54-in. to 78-in. pipe; or by more than ¾ in. for 84-in. pipe, and larger.

3.1.3 *Wall tolerances.* The minimum design thickness of pipe wall and the minimum thickness of concrete lining for each size of pipe shall be as shown in Table 3. At the spigot section, the concrete lining thickness may be less than shown in Table 3, provided that the interior surface of the lining at the spigot shall not depart from a true right cylinder projected from the interior surface of the lining in the body of the pipe. The thickness of walls shall be not less than the design thickness by more than ⅛ in. for 36-in. pipe, and smaller; by more than $\frac{3}{16}$ in. for 42-in. and 48-in. pipe; by more than ¼ in. for 54-in. to 72-in. pipe; or by more than ⅜ in. for pipe larger than 72 in.

Sec. 3.2—Design of Pipe

The reinforcement of the pipe shall consist of a welded steel cylinder surrounded by one or more cages of welded steel hoops, helically wound steel bar or wire, or welded wire fabric

SECTION 3—DESIGN

TABLE 3

*Requirements for Pipe of Various Sizes**

Pipe ID in.	Minimum Thickness	
	Total Pipe Wall in.	Concrete Lining in.
24	3½	1
30	3½	1
36	4	1
42	4½	1
48	5	1¼
54	5½	1¼
60	6	1¼
66	6½	1½
72	7	1½
78	7½	1½
84	8	1½
90	8	1¾
96	8½	1¾

* For pipe larger than 96 in. in diameter, dimensions and details of design shall be subject to approval by the purchaser.

properly spaced and supported with longitudinal reinforcing. The minimum thickness of the cylinder shall be 16 gage. The cross-sectional area of the circumferential steel in the cylinder and in the reinforcing cage or cages shall be such that the conditions required by the design methods in the appendix are met. If required by the purchaser, the manufacturer shall submit design calculations for approval prior to the manufacture of any pipe.

Sec. 3.3—Joint Rings

3.3.1 *General.* The steel bell and spigot joint rings shall be so designed and fabricated that when the pipe is laid and the joint completed, the gasket will be enclosed on four sides. Each ring shall be formed by one or more pieces of steel butt-welded together. The contact surfaces in the joint shall be such as not to cause cutting of the rubber gasket during installation. Welds on gasket contact surfaces shall be ground smooth and flush with the adjacent surfaces. The rings shall be expanded by a press beyond their elastic limits so that they are accurately sized.

3.3.2 *Tolerances.* On the finished pipe, the circumference of the inside bell ring contact surface shall not exceed the circumference of the outside spigot ring contact surface by more than $\frac{3}{16}$ in. for gaskets $\frac{21}{32}$ in. in diameter or by more than $\frac{1}{4}$ in. for gaskets greater than $\frac{21}{32}$ in. in diameter. The out-of-roundness of either contact surface, measured as the difference between the maximum and minimum joint ring diameters, shall not exceed 0.5 per cent of the average of these diameters. The minimum thickness of the completed bell rings shall be $\frac{3}{16}$ in. for 36-in. pipe, and smaller, and $\frac{1}{4}$ in. for pipe larger than 36 in. The rings shall conform to the details submitted by the manufacturer and approved by the purchaser.

3.3.3 *Protective coating.* The portions of the joint rings that will be exposed on the completed pipe shall be protected from corrosion by an approved coating.

Sec. 3.4—Rubber Gaskets

Joints shall be sealed with a continuous solid-ring rubber gasket having a circular cross section with a diametral tolerance of $\pm\frac{1}{64}$ in. Gaskets shall be of sufficient volume to fill substantially the recess provided when the pipe joint is assembled, so that the gasket will be compressed to form a pressure-tight seal. The gasket shall be the sole element depended upon to make the joint watertight.

Sec. 3.5—Fabrication of Steel Cylinders

3.5.1 *General.* The cylinders shall be formed by shaping and welding to-

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gether cut lengths or coils of specified material and thickness. The cylinders shall be accurately shaped to the size required, and the joint rings shall be welded to the ends before testing.

3.5.2. *Welding.* Butt-welding, lap-welding, or offset lap-welding, shall be used for the longitudinal and circumferential or helical seams. The sheets shall be closely fitted prior to welding and shall be firmly held during welding. If required, the manufacturer shall submit for approval the specific details of materials and methods he proposes to use before any welding is done.

3.5.3 *Hydrostatic test.* Each steel cylinder, with joint rings welded to its ends, shall be subjected to a hydrostatic test. When the cylinder is tested in a horizontal position, the stress shall be at least 20,000 psi, but not greater than 25,000 psi. When the cylinder is tested in a vertical position, the stress at the lower end shall be 25,000 psi. While under pressure test, all welds shall be thoroughly inspected and all parts showing leakage shall be marked. Cylinders that show any leakage under test shall be rewelded at the points of leakage and subjected to another hydrostatic test. The finished cylinder, with joint rings attached, shall not be used in the work unless it is completely watertight under the required test pressure.

3.5.4 *Cleaning steel surfaces.* Before the concrete is placed, steel surfaces shall be cleaned to remove loose or other foreign matter that would interfere with the bonding of the concrete.

Sec. 3.6—Fabrication of Reinforcement Cage

3.6.1 *Circumferential reinforcement.* The circumferential reinforcement shall either be steel bar or wire in helical or hoop form or be welded wire fabric shaped and lap- or butt-welded into cages. The quality of the welds and welding procedures shall be assured by the testing of a representative number of butt or lap welds to a test stress of 25,000 psi.

3.6.2 *Longitudinal reinforcement.* The circumferential reinforcement in cages shall be accurately spaced and rigidly assembled by the attaching of longitudinal bars securely, so that the cage is maintained in proper shape and position during the casting of the pipe.

3.6.3 *Placement.* The minimum distance between the circumferential reinforcing steel and the surface of the pipe shall be 1 in.

Sec. 3.7—Concrete for Pipe

3.7.1 *Proportioning.* The proportions of cement, fine aggregate, coarse aggregate, and water used in concrete for pipe shall be subject to the approval of the purchaser. The proportions shall be determined and controlled as the work proceeds in order to obtain homogeneous, dense, workable, durable concrete of specified strength in the wall of the pipe and a minimum of defects in the surface of the pipe. The proportions shall be those that will give the best overall results with the particular materials used for the work. A minimum of six bags of cement shall be used for each cubic yard of concrete. The water-cement ratio shall be such as to assure that the concrete will meet the strength requirements.

3.7.2 *Measurement of materials.* A barrel of cement shall be considered 4 cu ft or 376 lb, and a bag of cement shall be considered 1 cu ft or 94 lb. Cement in standard sacks need not be weighed, but bulk cement shall be weighed. Water for mixing shall be measured by volume or by weight.

SECTION 3—DESIGN

Concrete aggregates for each batch shall be measured separately by weighing. The proportions of aggregates shall be computed on both the saturated and surface-dry basis, and the water-cement ratio shall exclude the water absorbed by the aggregates. The equivalent unit weights for both fine and coarse aggregates shall be determined in accordance with the "Method of Test for Unit Weight of Aggregate" (ASTM Designation C29). The equipment and devices for weighing and measuring shall at all times be accurate within 1 per cent.

3.7.3 *Mixing.* The mixing shall be thoroughly done by a mixer of accepted type. Mixing time shall be consistent with the type of mixer used. Transit mixing shall not be used except by written authorization and under specific requirement of the purchaser.

3.7.4 *Standard test cylinders.* A set of at least four standard test cylinders shall be taken from each day's pour of the mixed concrete. Standard test cylinders shall be made in conformance with the "Method for Making and Curing Concrete and Compressive and Flexural Test Specimens in the Field" (ASTM Designation C31). The curing of the test cylinders shall be in conformity with the curing of the pipe.

3.7.5 *Testing cylinders.* All test cylinders shall be tested by an approved testing laboratory at the expense of the manufacturer, unless the manufacturer has approved testing facilities at the site of the work. In such event, the tests shall be made by the manufacturer in the presence of the purchaser and at the manufacturer's expense or, if permitted by the purchaser, certified test reports may be submitted by the manufacturer.

3.7.6 *Strength of concrete.* The design strength of concrete shall be the strength used in designing the pipe by the method described in the Design Appendix. The design strength of concrete shall be not less than 4,500 psi for vertically cast concrete or 6,000 psi for centrifugally cast concrete. The compressive strength of concrete cylinders shall equal or exceed $\frac{2}{3}$ of the design strength in 7 days and the design strength in 28 days. To conform to the requirements of this section, the average of any ten consecutive strength tests of cylinders representing each type of concrete shall be equal to or greater than the design strength, and no cylinder shall have a strength less than 80 per cent of the design strength. Damaged cylinders shall be discarded. Pipe made from concrete that does not meet the strength tests in accordance with the foregoing shall be subject to rejection.

3.7.7 *Forms.* The forms shall be of steel made with butt joints throughout and with the interior surface smooth and true. The forms shall be so constructed that the inner and outer forms, joint rings, and reinforcement shall be held in position throughout placing of the concrete and so designed that the pipe can be stripped from the forms rapidly and without damage to the pipe surfaces. Forms shall be sufficiently tight to prevent leakage of mortar, and they shall be stiff enough and so braced as to withstand, without deformation, all operations incident to the pouring and setting of the concrete. Forms shall be cleaned and oiled before each use.

3.7.8 *Placing concrete.* The transporting and placing of concrete shall be carried out by methods that will not cause the separation of concrete materials or the displacement of the steel cylinder and reinforcement from their proper positions in the form. Accepted methods of mechanical vibrating shall be used to compact the concrete in the forms and to secure satisfactory interior surfaces. Forms shall not be removed until the concrete has set sufficiently to avoid spalling or damage to the pipe during removal of the form.

Sec. 3.8—Curing of Pipe

3.8.1 *General.* The purpose of curing pipe as prescribed in the following sections is to obtain concrete of the strength specified for test cylinders under Sec. 3.7.6. The pipe shall be cured by steam or by water unless otherwise specifically permitted. Water curing and steam curing may be used interchangeably on a time-ratio basis of 4 hr of water to 1 hr of steam curing except that the water curing may be used only if the minimum ambient temperature exceeds 40F.

3.8.2 *Steam curing.* The pipe shall be placed in the steam-curing chamber or otherwise covered by a suitable enclosure that will allow proper circulation of steam. A delay period of from 1 to 4 hr shall be allowed before moist steam is admitted to contact the pipe. The temperature within the enclosure shall be gradually raised to at least 110F and to not more than 150F for a period of at least 24 hr. The delay period shall be included in the 24-hr period. Curing by steam shall be continuous except during a period sufficient to remove the forms or supporting rings. The forms shall not be removed until at least 6 hr after the begining of the curing. After this minimum 6-hr period, the pipes may be "tipped" from their bases, and curing shall be continued by either steam or water.

3.8.3 *Water curing.* The pipe shall be kept moist by intermittent water spraying for a period of at least 32 hr. The water-curing period shall be extended 1 hr for each hour in the first 24 during which the ambient air temperature is below 50F. Following this minimum period, they may be "tipped" from their bases but shall be kept continuously moist by intermittent spraying for an additional period of at least 3 days.

Sec. 3.9—Seal Coat

If the purchaser specifically orders a bituminous seal coat, the materials and application shall comply with the appropriate provisions of AWWA C104 (ANSI A21.4) insofar as they are applicable. The material shall be applied after the pipe is cured.

Section 4—Fittings and Special Pipe

Sec. 4.1—General

Fittings and special pipe shall include bends, tees, wyes, connections to main-line valves, closures, beveled pipe for curves, and pipe with outlets required for manholes, air valves, and blowoffs, as shown on the purchaser's drawings or as ordered by the purchaser. Fittings shall conform to the details furnished by the purchaser or, if required, to the details furnished by the manufacturer and approved by the purchaser. Fittings shall be either type

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as described in Sec. 4.2 and 4.3 at the option of the manufacturer and shall be designed for the same pressures as the pipe.

Sec. 4.2—Fittings (Type A)

Type A fittings are composed of steel cylinders, concrete or mortar lining, and reinforced concrete or mortar exterior coating. The steel for the cylinder shall be cut, shaped, and welded to form the properly shaped bend, tee, reducer, or other fitting. The welds shall be inspected, and the completed cylinder shall be tested for tightness by the dye penetrant method or other approved method, if specifically required by the purchaser. A cage or cages of steel reinforcement with approved cross-sectional areas shall be formed around the cylinder and openings. Longitudinal reinforcement sufficient for the additional stresses in the fitting walls shall be provided. The interior and exterior concrete or mortar shall be placed in an accepted manner. Curing shall be as specified in Sec. 3.8.

Sec. 4.3—Fittings (Type B)

Type B fittings are composed of cut and welded steel plate of a thickness to provide the design strength, with mortar coating on interior and exterior surfaces.

4.3.1. *Steel fabrication.* The steel for the fabricated steel plate fittings shall be cut, shaped, and welded so that the finished fitting shall have the required shape and interior dimensions. The deflection angle between adjacent segments of a bend shall be no greater than $22\frac{1}{2}$ deg. Adjacent segments shall be joined by lap or butt welding. Fabrication and welding shall conform to the requirements of Sec. 3.5 of this standard. The welds shall be inspected, and the completed cylinder shall be tested for tightness by the dye penetrant method or other approved method, if specifically required by the purchaser.

4.3.2 *Reinforcement.* Wire fabric reinforcing shall be applied to the interior and exterior surfaces of the fabricated fitting. The reinforcement shall be 2 × 4-in. W1 welded-wire fabric, held $\frac{3}{8}$ in. from the surfaces of the steel plate. The members on the 2-in. spacing shall extend circumferentially around the fitting, with ends overlapped 4 in. and tied together. Longitudinal splices shall be staggered.

4.3.3 *Mortar.* Steel plate fittings shall be lined with mortar at least $\frac{3}{4}$ in. thick at adapter ends, or outlets, but under no conditions shall the lining be less than $\frac{3}{8}$ in. thick. The exterior shall be coated with mortar at least 1 in. thick. The mortar shall contain no less than 1 part cement to 3 parts sand of a grading approved for the method of application used.

4.3.4 *Curing.* Mortar-lined and mortar-coated fittings in Sec. 4.3.3 shall be cured by water spraying, by steam, or by curing compounds. The curing compounds shall meet the requirements of "Liquid Membrane—Forming Compounds for Curing Concrete" (ASTM Designation C309), Type II, white pigmented.

Sec. 4.4—Curves, Bends, and Closures

Long radius curves and small angular changes in pipe alignment shall be formed by deflecting joints, by straight pipe with beveled ends, by bevel adapters, or by a combination of them. Pipe ends may be beveled up to 5 deg. Short-radius curves and closures shall be formed by fittings.

Sec. 4.5—Openings and Connections

Manholes and flanges, spigot or bell connections for air valves, blow offs, or connections to other pipe shall be built into the walls of the concrete pipe at locations shown on the purchaser's drawings or ordered by the purchaser. Wall openings shall be suitably reinforced. If required, the interior and exterior surfaces of structural steel connections shall be lined and coated with mortar.

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American Water Works Association

AWWA C303-70

AWWA Standard for

REINFORCED CONCRETE WATER PIPE—STEEL CYLINDER TYPE, PRETENSIONED

Section 1—General

Sec. 1.1—Scope

This standard covers the manufacture of circumferentially pretensioned reinforced concrete water pipe with a steel cylinder and rod reinforcement, in sizes from 10 to 42* in., inclusive and for design pressures to a maximum of 400 psi. The standard does not include specifications related to handling, delivery, laying, field testing, or disinfection of the pipe.**

Sec. 1.2—Definitions

In this standard the following definitions shall apply:

1.2.1. *Purchaser.* The word "purchaser" shall mean a person, firm, corporation, or government subdivision entering into a contract or agreement to purchase any materials or have any work performed according to these specifications.

1.2.2 *Contractor.* The word "contractor" shall mean the person, firm, or corporation executing the contract or agreement with the purchaser to furnish any materials or perform any work according to these specifications.

1.2.3. *Manufacturer.* The word "manufacturer" shall mean the person, firm, or corporation who actually manufactures the pipe, acting either directly as the contractor, or as a subcontractor or supplier. If the manufacturer is acting as a subcontractor under the contractor or otherwise as a supplier to the contractor, the obligations of the manufacturer under these specifications shall be considered as obligations of the contractor, and the contractor shall be responsible for their performance.

1.2.4. *Engineer.* The word "engineer" shall mean the engineer employed by the purchaser and acting as his representative, the purchaser himself acting as his own engineer, and their respective assistants and inspectors.

1.2.5. *ASTM.* The term "ASTM" shall mean the American Society for Testing and Materials. When specific ASTM specifications are cited, the designation shall be construed to refer to the latest revision under the same specification number, or to superseding specifications under a new number, except for provisions in the revised specifications which clearly are inapplicable.

* Larger diameters may be manufactured provided that the purchaser is in full accord with the design and will assume all responsibility for the proper installation to prevent injurious deflection.

** Refer to AWWA Manual M9, *Installation of Concrete Pipe* for details of installation.

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1.2.6. *AISI.* The term "AISI" shall mean the American Iron and Steel Institute.

1.2.7. *Approved.* The term "approved" shall mean having received the approval of the engineer.

1.2.8. *Design pressure.* The design pressure shall be the maximum sustained internal hydrostatic pressure to which the pipe is to be subjected. Generally, the design pressure for each pipe, or portion of the pipeline, shall be the operating pressure established by the hydraulic gradient or static head specified by the purchaser, whichever results in the greater pressure.

1.2.9. *Transient pressure conditions.* Transient pressure conditions shall be defined as overloads of relatively short duration due to the effects of water hammer or surge.

1.2.10. *External loads.* The term "external loads" shall mean all superimposed live and dead loads applied to the outside of the pipe after installation.

1.2.11. *Pipe diameter.* The term "pipe diameter" or "size" shall mean the nominal inside (waterway) diameter of the pipe.

Sec. 1.3—Essential Requirements

The pipe shall have the following principal features: a welded steel cylinder with sized steel joint rings welded to its ends; a lining of concrete or cement mortar centrifugally applied within the steel cylinder and spigot ring; reinforcement consisting of continuous steel rod wound helically around the outside of the cylinder at predetermined stress and securely fastened by welding to the steel joint ring at each end of the cylinder; a coating of dense mortar covering the cylinder and rods except for the necessarily exposed surfaces of the spigot joint ring; and a self-centering joint with a preformed gasket of rubber, so designed that the joint will be watertight under all conditions of service.

Sec. 1.4—Plans and Data To Be Furnished by the Purchaser

1.4.1. The purchaser shall designate the design and transient pressures applicable to each reach of pipeline for which the pipe shall be manufactured, as provided in Sections 1.2.8, 1.2.9, and 3.2.1. The external loading conditions and the method, or methods, of embedment and backfilling shall be specified.

1.4.2. At least one month prior to manufacture, the purchaser shall furnish the contractor plans and profiles showing: alignment and grades; the location of all outlets, connections, and special appurtenances; the design head or design pressures for each part of the pipeline; and such special details or information as are necessary for the manufacture of the pipe and fittings in accordance with this standard and with the specific requirements of the work for which the pipe is made.

Sec. 1.5—Supplementary Details To Be Furnished by Purchaser

When purchasing pipe under the provisions of this standard, the purchaser shall furnish supplementary specifications which shall include specific details concerning the following:

1.5.1. Standard used—that is, AWWA C303-70.

1.5.2. Whether an affidavit of compliance (Sec. 1.11) is required.

1.5.3. Manner of storage and delivery, if required of the contractor.

1.5.4. Whether submission of manufacturer's design calculations (Sec. 3.2.1) will be required.

1.5.5. Whether a tabulated layout schedule (Sec. 1.6.2) will be required.

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1.5.6. Identification marks required (Sec. 1.7).

1.5.7. Steel test reports (Sec. 1.10.3) and test specimens (Sec. 1.10.4).

1.5.8. Whether submission of rubber gasket material test reports (Sec. 1.10.5) will be required.

1.5.9. Type of cement required, if there is a preference (Sec. 2.1.1).

1.5.10. Whether quality control test reports on concrete lining (Sec. 1.10.2) will be required.

1.5.11. Whether aggregate samples (Sec. 2.3.) will be required.

1.5.12. Type of protective coating on exposed portions of joint rings (Sec. 3.3).

1.5.13. Whether submission for approval of details of materials and methods of welding (Sec. 3.5.2) will be required.

1.5.14. Whether details of specials and fittings are to be furnished by manufacturer (Sec. 4.1).

Sec. 1.6—Data To Be Submitted by Manufacturer

1.6.1. Drawings and schedules showing full details of reinforcement, concrete, and joint dimensions for the pipe shall be furnished by the manufacturer. All drawings and schedules shall be submitted for approval in quadruplicate, and one copy shall be returned to the manufacturer and one copy transmitted to the contractor after approval. Unless authorized by the purchaser, no pipe shall be manufactured until the drawings have been approved.

1.6.2. When specifically required, the data submitted by the manufacturer shall include a tabulated layout schedule, with reference to the stationing and grade line shown on the contract drawings. The schedule shall show pressure zones, each of which shall be designated by the design pressure and transient pressure applicable therein, and the point of change from one zone to the next shall be clearly indicated by station number. The diameter of the pipe, the design pressure and transient pressure, and area of steel (per linear foot of pipe wall) in the reinforcing rods and steel cylinder shall be listed for each portion of pipeline.

Sec. 1.7—Marking

Each special and each length of straight pipe shall have plainly marked inside on the bell or spigot end the identification marks specified by the purchaser. These shall include, as specified, either the pressure for which the pipe or special is designed or the area of effective circumferential reinforcement per foot of pipe wall. Special marks of identification, sufficient to show the proper location of the pipe or special in the line by reference to layout drawings and schedules specified under Sec. 1., shall be placed on the pipe if specifically required. All beveled pipe shall be marked with the amount of the bevel, and the point of maximum pipe length shall be marked at the end of the spigot.

Sec. 1.8—Inspection

1.8.1. The purchaser and his representatives shall have access to the work wherever it is in preparation or progress, and the manufacturer shall provide proper facilities for access and for inspection.

1.8.2. Inspection by the purchaser or his representatives, or failure of the purchaser or his representatives to provide inspection, shall not relieve the contractor or the manufacturer of his responsibility to furnish materials and to perform work in accordance with his standard.

1.8.3. Tests under Sec. 1.10 made by the purchaser, or his representatives, on material samples, shall be made without delay. If any sample fails to meet the requirements, the manufacturer shall be notified immediately. Material affected by the test results shall be set aside until final disposition of the material is settled. The manufacturer may then request a review of test procedures and additional tests on the material. Duplicate samples, the number of which is to be agreed upon, should be tested by the purchaser or his representative, and by the manufacturer. The manufacturer's tests shall be conducted by a commercial testing laboratory or in the manufacturer's laboratory, with proper certification. Tests by either party may be witnessed by the other. If the duplicate samples meet the test requirements, the material shall be accepted. If the material is rejected after retesting, the manufacturer shall pay all costs of retesting.

1.8.4. Material, fabricated parts, and pipe which for any reason do not conform to the requirements of this standard, will be subject to rejection at any time prior to final acceptance of the pipe. Rejected material and pipe shall promptly be removed from the site of the work.

Sec. 1.9—Material and Workmanship

All material furnished by the contractor or manufacturer shall be new and of the quality specified. All work shall be done in a thorough, workmanlike manner by mechanics skilled in their various trades.

Sec. 1.10—Tests

1.10.1. Each completed cylinder with joint rings welded to its ends shall be subjected to a hydrostatic test as specified herein under Sec. 3.5.4.

1.10.2. Quality control test of centrifugally applied concrete lining shall be made by the manufacturer by the method described in Sec. 3.6.3, and test reports shall be made available to the purchaser on request.

1.10.3. Mill test reports or plant test reports on each heat from which the steel is rolled shall be obtained by the manufacturer, and shall be made available to the purchaser on request.

1.10.4. The manufacturer shall provide test specimens cut from each shipment of steel for cylinders and for rods, if required by the purchaser.

1.10.5. Test reports showing the physical properties of rubber used in the gaskets, as specified in Sec. 3.4, shall be obtained by the manufacturer, and shall be made available to the purchaser on request.

1.10.6. The expense of the testing of materials and of submitting to the purchaser test reports in accordance with this standard and the purchaser's supplementary specifications referred to in Sec. 1.5, and the expense of testing the completed steel cylinder in accordance with Sec. 1.10.1, and testing concrete lining in accordance with Sec. 1.10.2, shall be borne by the manufacturer. All other tests shall be made by representatives of the purchaser at the purchaser's expense, except as otherwise specifically provided.

Sec. 1.11—Affidavit of Compliance

The purchaser may require an affidavit from the manufacturer that the pipe, specials, fittings, and other products or materials furnished under the purchaser's order comply with all applicable provisions of this standard.

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REINFORCED CONCRETE WATER PIPE

Section 2—Material Specifications

Sec. 2.1—Cement

2.1.1. Cement for concrete and mortar shall conform to the "Standard Specifications for Portland Cement" (ASTM Designation C150). Either Type I or Type II may be used unless the purchaser specifies a particular type. Sampling and testing shall conform to the individual ASTM specifications designated therein.

2.1.2. Satisfactory facilities shall be provided for identifying, inspecting, and sampling cement at the mill, warehouse, and the site of the work. The purchaser shall have the right to inspect the cement and obtain samples for testing at any of these points.

2.1.3. Cement shall be stored in a watertight, dry, well-ventilated structure.

2.1.4. Cement salvaged by cleaning cement sacks, mechanically or otherwise, shall not be used in the work. Cement containing lumps shall be rejected and shall immediately be removed from the site of the work.

2.1.5. If the temperature of the cement exceeds 150°F., it shall be stored until cooled to or below that temperature.

Sec. 2.2—Aggregates

Aggregates for concrete and for cement mortar shall consist of clean, hard, durable, and uncoated particles of natural sand or gravel, or shall be prepared from the product obtained by crushing stone, gravel, or other inert materials having similar qualities.

Aggregates shall conform to the requirements of the current "Standard Specifications for Concrete Aggregates" (ASTM Designation C33), with the exception that the gradation may be modified to provide a lining and coating of maximum density. In no case shall any of the aggregate used in the lining of pipe in the diameter range 10–16 in. be retained on a No. 4 (4.6 mm) US Standard sieve, nor shall any of the aggregate used in the lining of pipe in the diameter range 18–42 in. be retained on a ½ in. (12.7 mm) sieve.

Sec. 2.3—Samples of Aggregates

At least 4 weeks prior to mixing concrete or cement mortar, the manufacturer, if required, shall provide in suitable containers, for preliminary approval, samples of not less than 1 cu ft each of the aggregate to be used in the lining and coating. All samples shall be plainly labeled to indicate the source of the material, the date, and the name of the collector. Methods of sampling aggregates shall be in accordance with the "Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials" (ASTM Designation D75).

Sec. 2.4—Water

Water used for concrete and for cement mortar, and for curing pipe, shall be fresh water and shall be clean and free from oil, acid, strong alkalis, or vegetable matter.

Sec. 2.5—Steel for Cylinders and Special Fittings

2.5.1. Steel sheets for pipe cylinders and special fittings shall conform to the "Specifications for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality, Grade C" (ASTM Designation A570).

2.5.2. Steel plates for pipe cylinders and special fittings shall conform to the

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"Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality, Grade B, C, or D" (ASTM Designation A283), or to the "Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates of Flange and Firebox Qualities, Grade B or C" (ASTM Designation A285).

Sec. 2.6—Steel for Rod and Wire-Mesh Reinforcement

2.6.1. The steel rod for circumferential reinforcement in the pipe shall be plain round rods conforming to the "Specification for Carbon Bars Subject to Mechanical Property Requirements" (ASTM Designation A306), Grade 80; or conforming to the "Specification for Deformed Billet-Steel Bars for Concrete Reinforcement" (ASTM Designation A615), Grade 40, except that (1) bars shall be plain round bars and the requirements of Sec. 6, 7, and 14.3 shall not apply; (2) intermediate diameter bars shall meet the require-designation; and (3) bars of diameter ments for the next smaller bar number less than No. 3 shall meet the requirements for No. 3 bar.

2.6.2. Wire-mesh reinforcement for mortar coating and lining of fittings shall conform to the "Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement" (ASTM Designation A185).

Sec. 2.7—Steel for Joint Rings

2.7.1. Steel strips for bell rings less than $\frac{1}{4}$ in. thick shall conform to the "Specification for Hot-Rolled Carbon Steel Sheets and Strip. Structural Quality, Grade A" (ASTM Designation A570). Steel which meets the requirements of AISI-1012 for chemical components will be acceptable provided it conforms to ASTM Designation A570, Grade A, in other respects.

Sec. 2.8—Steel Castings for Fittings

Steel castings for fittings shall conform to the "Specifications for Mild-to Medium-Strength Carbon-Steel Castings for General Application, Grade 70-36, Normalized" (ASTM Designation A27).

Section 3—Fabrication of Pipe

Sec. 3.1—General Requirements

3.1.1. Pipe shall be furnished in diameter increments of 2 inches for sizes 10 in. through 20 in., and in 3-inch increments for sizes 21 in. through 42 in.

3.1.2. The manufacturer shall furnish standard pipe uniform in length within a range of from 24 to 40 feet, except that the laying length of pipe 21 in. in diameter and smaller shall not exceed 32 feet. Special short sections may be furnished to meet special conditions. Specials such as bends, reducers, closure pieces, and other special fittings may be made in shorter lengths.

3.1.3. Throughout lining placement and all subsequent manufacturing operations, adequate means, such as gage rings, stiffener rings, and bracing, shall be used as necessary to maintain the out-of-roundness of the cylinder at any transverse section in the pipe, measured as the difference between maximum and minimum diameters, within 1.0 per cent of the average of these diameters. Pipe ends shall be square with the axis of the pipe within ¼ in. except when beveled ends are furnished.

3.1.4. Measured from the inside surface of the cylinder, concrete or cement mortar linings shall have the following respective thicknesses and tolerances:

Pipe Diameter Range	Lining Thickness	Tolerance
10–16 in.	½ in.	± ⅛ in.
18–42 in.	¾ in.	± 1/16 in.

3.1.5. The minimum thickness of the cement mortar coating shall be ¾ in. over the rod reinforcement or 1 in. over the cylinder, whichever results in the greater thickness of coating.

Sec. 3.2—Design of the Pipe

3.2.1. *General.* The purchaser or engineer shall state the design pressure requirements. The design procedure is set forth in Appendix "A" hereof. The procedure in Appendix A in which the design pressure is applied in accordance with formula (1) provides a capacity for transient pressure of at least 50 per cent of the design pressure. Should the transient pressure exceed 50 per cent of the design pressure at any point in the pipeline, the required allowances for transient pressure shall be stated in the plans and data to be furnished by the purchaser pursuant to Sec. 1.4. If required by the purchaser or engineer, the manufacturer or contractor shall submit design calculations for approval prior to the manufacture of any pipe.

3.2.2. *Steel cylinder and rod reinforcement.* The average circumferential stress in the steel cylinder and rod reinforcement of the pipe at design pressure shall not exceed 16,500 psi nor 50 per cent of the specified minimum yield strength of the steel used in the cylinder when computed according to formula (1) of Appendix A. Under the combined effect of the design pressure and transient pressure, the average circumferential stress in the steel cylinder and the rod reinforcement of the pipe shall not exceed 75 per cent of the specified minimum yield strength of the steel used in the cylinder when computed according to formula (2) of Appendix A. The area of rod reinforcement shall not be greater than 60 per cent of the total area of circumferential reinforcement. The area of rod reinforcement shall be not less than 0.23 sq in. per linear foot, nor shall the center-to-center rod spacing exceed 2 in.

The area of rod reinforcement in square inches per linear foot of pipe wall shall be numerically equal to at least 1 per cent of the inside diameter of the pipe in inches. The design clear space between rods shall not be less than 1 diameter of the rod used, and the rod shall not be less than 7/32 in. in diameter. The minimum cylinder thickness shall be as follows:

Pipe Diameter Range	Minimum Cylinder Thickness
10–16 in.	16 gage
18–21 in.	15 gage
24–33 in.	14 gage
36–39 in.	13 gage
42 in.	12 gage

Steel cylinders shall be made to the designed diameter with the following circumferential tolerances:

Pipe Diameter Range	Tolerance on Taped Circumference
10–16 in.	± 3/16 in.
18–42 in.	± ¼ in.

Sec. 3.3—Joint Rings

The steel bell-and-spigot joint rings shall be so designed and fabricated that, when the pipe is laid, it will be self-centered. Each ring shall be formed by one or more pieces of steel butt-welded together, either by a resistance welder or by a hand-electric weld, and the weld surface shall be ground flush with the adjacent surface. The rings shall be expanded by a press beyond their elastic limits so that they are accurately sized. On the finished pipe, the circumference of the inside bell ring contact surface shall not exceed the circumference of the outside spigot ring contact surface by more than $\frac{3}{16}$ in. The minimum thickness of the completed bell rings shall be 10 gage for pipe sizes 10 in. through 16 in., and $\frac{3}{16}$ in. for larger sizes. The cross-sectional area of the bell ring plus the cross-sectional area of the rod reinforcement over the bell shall provide a total cross-sectional area at least equal to that furnished in a like length of pipe wall in the barrel of the pipe between joint rings. The rings shall conform to the details submitted by the manufacturer and approved by the engineer. The joint rings shall be so designed that, when the pipe is laid and the joint completed, the gasket will be tightly enclosed on all four sides and confined under compression adequate to ensure watertightness under the specified conditions of service. The contact surfaces shall be smooth, to prevent cutting of the rubber gasket during installation. The portions of the joint rings which will be exposed on the completed pipe prior to installation shall be protected from corrosion by an approved coating.

Sec. 3.4—Rubber Gaskets

3.4.1. The joint shall be sealed with a continuous solid ring gasket of circular cross-section made of a special composition rubber of such volume as to substantially fill the recess provided for it. The gasket shall be the sole element depended upon to make the joint watertight and shall have smooth surfaces free from pitting, blisters, porosity, and other imperfections. The rubber compound shall contain not less than 50 per cent by volume of first-grade natural crude or first-grade synthetic rubber. The remainder of the compound shall consist of pulverized fillers free from rubber substitutes, reclaimed rubber, and deleterious substances. The compound shall meet the following physical requirements when tested in accordance with the respective ASTM specification designated.

3.4.2. *Tensile strength.* The tensile strength of the compound shall be at least 2,700 psi for natural-rubber gaskets and 2,000 psi for synthetic rubber gaskets—"Method of Test for Tension Testing of Vulcanized Rubber" (ASTM Designation D412).

3.4.3. *Elongation at rupture.* The elongation at rupture shall be at least 400 per cent for natural-rubber gaskets and 350 per cent for first-grade synthetic-rubber gaskets—"Methods of Test for Tension Testing of Vulcanized Rubber" (ASTM Designation D412).

3.4.4. *Specific gravity.* The specific gravity shall not vary more than ±0.05 within the range 0.95–1.45—"Methods for Chemical Analysis of Rubber Products" (ASTM Designation D297).

3.4.5. *Cold flow.* The percentage of cold flow shall not exceed 20. The cold-flow determination shall be made in accordance with "Methods of Test for Compression Set of Vulcanized Rubber" (ASTM Designation D395 Method B), with the exception that the disc shall be a $\frac{1}{2}$ in. thick section of the rubber gasket stock.

3.4.6. *Tensile strength after aging.* The tensile strength of the compound, after being subjected to an accelerated aging test for 96 hours in air at 158°F.,

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shall not be less than 80 per cent of the tensile strength before aging—"Standard Method of Test for Accelerated Aging of Vulcanized Rubber by the Oven Method" (ASTM Designation D573).

3.4.7. *Shore durometer.* The shore durometer hardness shall be in the range of 55 ± 5 and shall be determined in accordance with "Method of Test for Identation Hardness of Rubber and Plastics by Means of a Durometer" (ASTM Designation D2240, with the exception of Section 4 thereof). The determination shall be taken directly on the gasket. The presser foot shall be applied on a disc cut from the gasket stock which has a minimum diameter of ½ in. and a thickness of ½ in.

3.4.8. If required by the engineer, the contractor shall submit test reports showing the physical properties of the rubber compound used in the manufacture of the gaskets.

Sec. 3.5—Fabrication of Steel Cylinders

3.5.1. The steel cylinders shall be formed by shaping and welding together cut lengths or coils of specified material and thickness.

3.5.2. Helical or transverse and longitudinal seams shall be butt-welded, or offset butt- or lap-welded with the offset edge on the inside of the cylinder. All welds shall be made downhand by the manual or automatic shielded-arc process. Welding shall be done so that there is thorough fusion and complete penetration. Prior to welding, the sheets or plates shall be fitted closely and during welding shall be held firmly. The manufacturer shall submit for approval, if required, the specific details of materials and methods he proposes to use before any welding is done.

3.5.3. Specimens for bending tests of welds shall be furnished by the contractor to the engineer as required. The number of cylinders from which test specimens are required to be cut shall not exceed one in every 3,000 ft of pipe, provided that, if tests indicate the welding is unsatisfactory, the contractor shall furnish additional samples as required by the engineer. Cylinders from which test specimens have been cut may be patch welded in an approved manner and used in the work. The test specimens, procedure, and results shall conform to the requirements of the "Method for Guided Bend Test for Ductility of Welds" (ASTM Designation E190), except that the die width shall be ¾ in. and the plunger dimension shall be less than ¾ in. by approximately twice the maximum metal thickness plus ⅛ in. The weld shall not be machined. The specimen shall not fracture completely, and no cracks exceeding $\frac{1}{16}$ in. in any direction shall be present in the weld metal or between the weld metal and the pipe metal. Cracks that originate at the edges of the specimen and that are less than ⅛ in. long shall not be cause for rejection. The expense of the welding tests shall be borne by the purchaser.

3.5.4. Each steel cylinder, with joint rings welded to its ends, shall be subjected to a hydrostatic test under water pressure which stresses the steel to a unit stress of at least 20,000 psi but not greater than 25,000 psi. While under pressure test, all welds shall be thoroughly inspected and all parts showing leakage shall be marked. Cylinders which show any leakage under test shall be rewelded at the points of leakage and subjected to another hydrostatic test. The finished cylinder, with joint rings attached, shall not be used in the work unless it is completely watertight under the required test pressure. Further welding on tested cylinders will not be permitted unless tested as required by Sec. 4.5, or as approved by the engineer.

Sec. 3.6—Centrifugally Applied Concrete or Cement Mortar Lining

3.6.1. *General.* Before the steel cylinder is wound with rod reinforcement, a concrete or cement mortar lining shall be centrifugally cast within the cylinder to provide a dense, hard, smooth lining of the thickness called for in Sec. 3.1.4. Cement mortar for lining shall consist of one part of cement to not more than three parts of fine aggregate by weight, and water. Only enough water to obtain proper characteristics of the material shall be used, and the total free water content of the mixed mortar shall not exceed 7-½ gallons per sack of cement. Concrete for lining shall consist of cement, fine aggregate, coarse aggregate, and water. The minimum cement content shall be 7 sacks per cubic yard of concrete.

3.6.2. *Mixing and placing.* The cement and aggregate shall be batched by weighing. After the final tempering of the mix with water, the material shall be mixed for not less than one-half minute in pan or turbine type mixers, or for not less than one minute in paddle type mixers. There shall be no retempering of the mix once the concrete or mortar has been discharged from the mixer. All water used in the mix shall be metered, and allowance shall be made for any free moisture present in the sand. The temperature of the mix shall not be less than 40°F at the time of placement. Immediately prior to application of the mortar or concrete lining, all loose mill scale, excessive rust, oil, grease, and other foreign substances shall be removed from all steel surfaces to which the lining is to be applied. End gage rings shall be securely attached to the pipe ends to control the lining thickness, to prevent mortar leakage, to hold back the lining in the bell ring, and to stiffen and hold the pipe ends round. The lining shall terminate flush with the end of the spigot ring and shall terminate the distance in from the end of the bell ring called for on the approved detailed shop drawings. The end gage rings shall remain in place until the end of the primary cure unless other measures at least equally effective are taken to stiffen and hold the pipe ends round. Stiffener rings, if used, shall also remain in place during the primary cure unless equivalent support is provided by other means. Immediately upon completion of the lining operation, the pipe shall be moved to the primary curing area. Care shall be exercised at all times during handling to prevent damage to the lining.

3.6.3. *Strength and quality control of concrete lining.* Concrete used for lining shall have a compressive strength of not less than 3,000 psi in 7 days and 4,500 psi in 28 days. A minimum of one set of three cylinders from each day's pour shall be prepared and tested. Concrete samples may be prepared by omitting sufficient water from the production mix to obtain a 1–3-in. slump and the cylinders shall be prepared from this sample in accordance with the "Standard Method for Making and Curing Concrete Compression and Flexure Test Specimens in the Field" (ASTM Designation C31), and shall be tested in accordance with the "Standard Method of Test for Compressive Strength of Molded Concrete

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Cylinders" (ASTM Designation C39). If laboratory facilities are not available at the plant, then the tests shall be made by an approved testing laboratory. As an alternate, a small spinning device may be used, with a steel cylinder dimensioned in accordance with the standard test cylinder as described in ASTM Designation C31, and the concrete may be spun into the cylinder with a thickness of at least 1½ in. The concrete shall be removed from the mix in accordance with the "Standard Method of Sampling Fresh Concrete" (ASTM Designation C172). Curing of test specimens shall be the same as curing the pipe. The specimens shall then be tested in accordance with ASTM Designation C39, using the net concrete area to determine the compressive strength.

3.6.4. *Curing prior to placement of rod reinforcement.* Linings shall be either steam cured or moist cured at the option of the manufacturer, except that moist cure may be used only if the minimum ambient temperature exceeds 40°F continuously during the required minimum curing period. In either case, linings shall be kept continuously moist until the completion of the minimum curing period, after which the pipe may be wound with the rod reinforcement.

3.6.4.1. *Steam cure.* Steam curing may begin immediately on arrival of the pipe at the primary curing area, but the temperature of the pipe shall not exceed 90°F for three hours or until the mortar has taken its initial set, whichever occurs first. The ambient vapor shall then be maintained at a temperature between 110°F and 150°F for a minimum curing period of six hours.

3.6.4.2. *Moist cure.* On arrival at the primary curing area, pipe ends shall be covered with plastic or wet burlap for a minimum period of 24 hours, and the ambient temperature shall be maintained continuously above 40°F during such period. The moist curing period shall be continued one hour for each hour, during the first 24, during which the ambient temperature is below 50°F.

Sec. 3.7—Placing of Rod Reinforcement

After the lining has been cured as specified in Sec. 3.6.4, circumferential reinforcing rod shall be wound helically around the cylinder under a tensile stress equal to from 110 per cent to 125 per cent of the difference between the specified minimum yield points of the rod and cylinder. An accurate and dependable device shall be provided for tensioning and for measuring and indicating the tension in the rod reinforcement during the winding operation.

On standard pipe, circumferential rod reinforcement shall be continuous from the bell to the spigot ring. All splices shall be lap welded, butt welded, or otherwise spliced so as to be equal in strength to the minimum specified strength of the rod. Rods shall be welded only to the joint rings and shall not be welded to the cylinder. The welded connections to the joint rings shall be sufficiently strong and secure to anchor the rod against its specified minimum yield strength. The number of coils of rods along any 2 ft length of cylinder shall not be less than required by the design.

As the circumferential rod reinforcement is wound, a portland cement paste composed of one sack of cement to six (6) gallons of water shall be applied to the rod or to the cylinder just ahead of the rod so that the portion of the rod bearing against the cylinder will be coated with cement paste. Up to, but

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not exceeding, ten (10) gallons of water may be used per sack of cement in hot, arid regions. A retarder of a type approved by the engineer may be used in the mix. Immediately prior to placement of the cement paste, all loose mill scale, excessive rust, oil, grease, and other foreign substances shall be removed from all steel surfaces with which the cement paste will be in contact.

Sec. 3.8—Cement Mortar Coating

3.8.1. *General.* After the lined cylinder has been wrapped with tensioned rod reinforcement, an exterior mortar coating shall be applied. Mortar for coating shall be composed of one part cement and not more than three parts fine aggregate which shall be batched by weighing, and a minimum water content of 6 per cent of the total dry weight of cement and aggregate. The cement and fine aggregate shall conform to Sec. 2.1 and Sec. 2.2, respectively. Clean "rebound material" may be reused as fine aggregate provided it is used within 30 minutes from the time it was mixed and it does not exceed 50 per cent of the aggregate content of the mortar mixture. "Rebound material" shall be defined as mortar that does not adhere to the pipe during the application of the coating. Immediately prior to placement of the cement paste required by Sec. 3.8.2, all loose mill scale, excessive rust, oil, grease, and other foreign substances shall be removed from all surfaces with which the cement paste will be in contact.

3.8.2. *Mixing and placing.* The cement and aggregate shall be batched by weighing and mixed not less than ½ minute in pan or turbine type mixers, and for not less than 1 minute in paddle type mixers. There shall be no addition of water once the mortar has been discharged from the mixer. All water used in the mix shall be metered, and allowance shall be made for any free moisture present in the sand. The temperature of the mortar mix shall not be less than 40°F at the time of placement.

Cement mortar coating shall be deposited by high velocity impact using an approved method so that a dense, durable coating of thickness at no point less than specified in Sec. 3.1.5 will be obtained. The finished coating shall be dense and firm throughout, and shall be in intimate contact with all steel surfaces. The coating shall extend to the end of the bell ring and shall be struck off at the end of the bell ring in the shape shown on the approved detailed shop drawings. The coating shall terminate the distance in from the spigot ring called for on the approved detailed shop drawings. Immediately preceding application of the coating, a cement paste composed of one sack of portland cement to six (6) gallons of water shall be applied uniformly over the steel surfaces and the previously applied cement paste required under Sec. 3.7. Up to, but not exceeding, ten (10) gallons of water may be used per sack of cement in hot, arid regions. A retarder of a type approved by the engineer may be used in the mix.

Within a period of 8 hours after application of mortar coating, the pipe shall be handled only with belt slings or other suitable means to prevent damage to the coating. The pipe may not be rolled until curing has been completed. Dropping or bumping of pipe will not be permitted.

Sec. 3.9—Curing of Completed Pipe

3.9.1. *General.* The completed pipe shall be cured by moist curing or by

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steam curing methods. Moist and steam curing may be used interchangeably on a time ratio basis of 4 hours of moist curing to 1 hour of steam curing except that moist curing may be used only if the minimum ambient temperature exceeds 40°F. All freshly coated pipe shall be adequately protected from freezing or excessively high temperatures.

3.9.2. *Moist cure.* After the pipe has been coated, its inner and outer surfaces shall be kept continuously moist by intermittent sprinkling of the pipe for a period of at least 6 days or 144 hours before the pipe is moved to the job site. Moist curing shall begin as soon as the pipe can be sprinkled without damage to the coating. The moist curing period shall be continued one hour for each hour, during the first 24, during which the ambient temperature is below 50°F.

3.9.3. *Steam cure.* The pipe shall be placed in a steam curing chamber or otherwise covered by a suitable enclosure that will allow proper circulation of steam for curing both the lining and the coating. Steam curing of the pipe may begin immediately after the coating operation and, in any event, shall begin within 6 hours thereafter, but the temperature of the pipe shall not exceed 90°F until the cement mortar coating has taken its initial set, or until a period of 3 hours has elapsed, whichever occurs first. The pipe shall then be kept moist at a temperature between 110°F and 150°F for a minimum continuous period of 36 hours.

3.9.4. *Additional cure.* Pipe stored in the manufacturer's yard after curing shall be additionally moist cured if necessary to prevent excessive drying until delivery to the job site.

Sec. 3.10—Repair of Lining and Coating

The portion of the lining or coating to be repaired shall be removed to the depth of the defective concrete or mortar. For coating repairs, additional mortar shall be removed from around the reinforcing rods as necessary to provide for keying of the repair mortar to the reinforcement assembly. The mortar used for repairs shall have the same proportion of cement and sand as specified for mortar in Sec. 3.6.1 and Sec. 3.8.1, and shall be placed by mechanical means or by hand application to the full required thickness. Repairs shall be cured as specified in Sec. 3.9 or by prompt application of a clear or white-pigmented sealing compound conforming to the "Specification for Liquid Membrane-Forming Compounds for Curing Concrete" (ASTM Designation C309). Repaired pipe shall not be shipped or handled for a minimum of 24 hours following application of sealing compound, or following completion of curing by the methods. Continued care shall be exercised thereafter to protect the repaired areas and to maintain the membrane seal if sealing compound has been applied. If in any section of pipe the defects or injuries are so numerous or extensive that, in the judgment of the purchaser or the engineer, it would be unsatisfactory to make separate repairs of such defects or injuries, the lining or coating, as the case may be, in such section of pipe shall be removed in its entirety and replaced. Where the entire lining is removed, such removal and the replacement and primary curing of the lining shall be completed before the reinforcement rod is applied to the steel cylinder. In the event the defects or injuries which, for the reasons stated

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above, would require removal of the entire lining are not detected or do not occur until after the reinforcement rod has been applied, then the affected section of pipe shall be rejected. Where defects in the lining are detected, or injuries thereto occur, before the reinforcement rod has been applied to the cylinder, and separate repairs are permitted, such repairs and the primary curing thereof shall be completed before the reinforcement rod is applied.

Section 4—Specials and Fittings

Sec. 4.1—General

The manufacturer shall furnish all fittings and special pieces required for closures, curves, bends, branches, manholes, air valves, blowoffs, and connections to main-line valves and other piping shown on the contract drawings or ordered by the purchaser. Specials shall conform to the details furnished by the purchaser, or, if required, to the details furnished by the manufacturer and approved by the purchaser. Unless otherwise prescribed or approved by the purchaser, special fittings shall be fabricated of welded steel sheet or plate, and shall be lined and coated with cement mortar. The mortar coating shall be reinforced with wire mesh as hereinafter specified and the mortar lining shall be similarly reinforced where prescribed. The thickness of the sheet or plate, as a minimum, shall conform to the design requirements of Sec. 3.2, and to the further requirement that the maximum circumferential stress in the fitting at design pressure shall not exceed 15,000 psi. Notwithstanding the provisions of Sec. 3.2 as to minimum cylinder thickness, the minimum thickness of sheet or plate for fittings shall be as follows:

Range of Maximum Fitting Diameter	Minimum Thickness of Sheet of Plate
10–21 in.	10 gage
24–36 in.	7 gage
39–42 in.	¼ inch

Sec. 4.2—Specials

4.2.1 The steel for the fabricated steel sheet or plate specials shall be cut, shaped, and welded so that the finished special shall have the required shape and interior dimensions. The deflection angle between adjacent segments of a bend shall be not greater than 22½ deg. Adjacent segments shall be joined by lap or butt welding. Fabrication and welding shall conform to the requirements of Sec. 3.5 and to such additional requirements for welding steel plate as the purchaser specifically prescribes.

4.2.2 Crimped wire mesh reinforcing shall be applied to the exterior surfaces of the fabricated special. It shall be 2 × 4 in., 13-gage, welded wire fabric, held ⅜ in. from the surfaces of the steel sheet or plate. Plain 2 × 4 in. 13-gage, welded wire mesh shall be applied by welding to the interior steel surface of fittings 27 in. in diameter and larger which are to be cement mortar lined. Wire mesh reinforcing will not be required for centrifugally placed concrete or cement mortar lining. The members on the 2 in. spacing shall extend circumferentially around the special with ends overlapped 4 in. and tied together. Longitudinal splices shall be staggered.

4.2.3 Steel plate specials shall be lined with mortar to a thickness compatible with the pipe, but under no conditions shall the lining be less than

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$\frac{3}{8}$ in. thick. The exterior mortar coating shall be at least 1 in. thick. The mortar shall contain not less than 1 part cement to 3 parts sand, of a grading approved for the method of application used, and shall conform to the applicable provisions of Sec. 3.8.

4.2.4 Mortar-coated specials shall be cured by moist spraying or by steam, as specified in Sec. 3.6.4 and Sec. 3.9, or by an approved membrane.

Sec. 4.3—Curves, Bends, and Closures

Slight deflections for horizontal and vertical angle points, long-radius curves, or alignment corrections may be made by unsymmetrical closure of joints, provided that the interior joint spaces are not at any point less than the minimum or more than the applicable maximum specified in the following tabulation:

Pipe Diameter Range	Interior Joint Space *Normal*	*Minimum*	*Maximum*
12–21 in.	$\frac{1}{4}$ in.	$\frac{1}{8}$ in.	1 in.
24–42 in.	$\frac{1}{2}$ in.	$\frac{1}{4}$ in.	$1\frac{1}{4}$ in.

Special beveled joint designs may be used with a maximum deflection of 5 deg per joint, provided they comply with the requirements of Sec. 3.3. Short-radius curves and closures shall conform to the provisions of Sec. 4.1 and Sec. 4.2.

Sec. 4.4—Openings and Connections

Manholes and flanges, spigot or bell connections for air valves, blowoffs, or connections to other pipe shall be built into the walls of the concrete pipe at locations shown on the contract drawings or ordered by the purchaser. Openings in special fittings or pipe shall be reinforced with collars, wrappers, or crotch plates. The reinforcement rods on the pipe shall be securely fastened by welding on each side of the outlet. The casting or fabricated outlet shall be welded to the saddle plate or saddle neck and cylinder after the hole is cut through the plate, cylinder, and concrete. Alternative outlet designs may be used, if specifically approved by the purchaser. All materials for openings and connections, and the fabrication thereof, shall conform to the provisions set forth elsewhere in this standard, so far as applicable.

Sec. 4.5—Testing

The seams in angle pipe, short radius bends, and special fittings shall be tested by the air-soap method using air at a pressure of 5 psi; except that, at the option of the manufacturer, the dye-penetrant method may be substituted. However, if the fitting is from cylinders which have been previously hydrostatically tested, no further test will be required on seams so tested. At the option of the manufacturer, hydrostatic testing of fittings to 120 per cent of the design pressure plus the estimated maximum increment of pressure due to transient conditions may replace the tests described above. Any defects revealed by any of the alternate test methods shall be repaired by welding and the specified testing repeated until all defects have been eliminated.

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SPECIFICATIONS FOR PRESTRESSED CONCRETE CYLINDER PIPE WITH RUBBER AND STEEL JOINT

Produced According to
AWWA Standard C-301-72

TYPE OF PIPE

The pipe shall be of the type known as Prestressed Concrete Cylinder Pipe. It shall be reinforced with a welded steel cylinder with steel joint rings welded to its ends. The steel cylinder shall be lined with concrete, wrapped with a high tensile strength wire under tension and coated with a dense covering of cement mortar. Each pipe shall be constructed with a self-centering expansion joint sealed with a rubber gasket and capable of caring for normal movement due to earth settlement and extremes of temperature.

DIMENSIONS

The dimensions of the straight pipe shall be in accordance with the table on the facing page. Special pipe for bends, reducers, closure pieces and other fittings may be made in shorter lengths, as required.

The pipe shall be round and true. The average internal diameter of the straight pipe shall not be less than the nominal diameter by more than 1/4" for pipe 36" and smaller; by more than 3/8" for pipe 42" and 48"; or by 1/2" for pipe 54" and larger.

PIPE DESIGN

The diameter of prestress wire used, its centerline spacing and the tension under which it is wound around the core shall be such that the core will be sufficiently compressed to withstand an internal hydrostatic pressure equal to at least 1.25 times the design operating pressure without inducing tensile stress in the core. The elastic and inelastic deformations of the concrete and steel shall be taken into consideration. The gross wrapping stress in the high tensile wire shall not exceed 75% of the minimum ultimate tensile strength of the wire. The maximum centerline spacing shall be 1-1/2". Minimum centerline spacing of wire shall be that which produces a clear distance between wires of 3/16". The minimum diameter of wire used shall be No. 8 gage.

Steel sheets and steel wire of qualities other than those indicated below may be used, provided the design of the pipe is based upon the respective physical properties of the materials.

The core shall not be wrapped with wire until the concrete has reached the specified strength. The initial compression induced in the concrete shall not exceed 55% of its compressive strength at the time of wrapping.

PIPE JOINTS

The joint shall be sealed by a rubber gasket in such a manner that it will remain tight under all conditions of service, including movement due to expansion, contraction and normal settlement. Each length of pipe shall be provided with bell and spigot ends formed by steel joint rings welded to the cylinder. The spigot ring shall be lined with concrete on its interior surface and the bell ring shall be covered with mortar on its exterior surface. Portions of the joint rings which will be exposed after the pipe is manufactured shall be protected from corrosion by an approved coating. The spigot ring shall have a groove for the purpose of receiving, holding and protecting the gasket. The joint surfaces shall be of such shape and dimensions that the joints will be self-centering when the pipe is laid so that the gasket will not be required to support the weight of the adjoining pipe.

Steel of flat section for bell rings 3/16" thick shall be used on pipe sizes up to and including 36" and shall conform to "Standard Specification for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality", Grade C, ASTM Designation A-570.

Steel plate for bell rings 1/4" or more in thickness and special shapes for spigot joint rings shall conform to "Standard Specifications for Carbon Steel Bars Subject to Mechanical Property Requirements", Grade 50, ASTM Designation A-306.

The gasket sealing the joint shall be made of a special composition rubber having a texture to assure a watertight and permanent seal and shall be the product of a manufacturer having at least five years' experience in the manufacture of rubber gaskets for pipe joints. The gasket shall be a continuous ring of suitable cross-section and of such size as to fill the groove on the spigot joint ring when the pipes are laid. The rubber gasket shall be the sole element depended upon to make the joint watertight and shall have smooth surfaces free from pitting, blisters, porosity and other imperfections. Each gasket shall be subjected to a stretch of 100% and examined for any defects while in the stretched condition. Cement mortar or plastic materials used to finish the joint shall not be depended upon for watertightness.

Synthetic isoprene gaskets shall comply with the following physical requirements:

Tensile strength, min. psi	3000
Elongation at rupture, min. percent	425
Compression set, max. percent	18
Accelerated aging	
Tensile strength retained, min. percent of original	85
Elongation retained, min. percent of original	80
Water absorption	
Volume and weight increase, max. percent	5
Durometer hardness, points	60±5

The physical properties of the gaskets shall be determined in accordance with the following methods:

Tensile Strength	"Tension Testing of Vulcanized Rubber", ASTM Designation D-412
Elongation	"Tension Testing of Vulcanized Rubber", ASTM Designation D-412
Compression Set	"Compression Set of Vulcanized Rubber", ASTM Designation D-395, Method B, age 22 hours at 70°C
Accelerated Aging	"Oven Test for Aging of Rubber", ASTM Designation D-573, age 96 hours at 70°C
Water Absorption	"Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids", ASTM Designation D-471, age 48 hours at 70°C
Durometer Hardness	"Indentation Hardness of Rubber and Plastics by Means of a Durometer", Type A, ASTM Designation D-2240

STEEL CYLINDER

The steel cylinder shall be made of hot rolled steel sheets not lighter than No. 18 gage U.S. Standard for 16" through 48" and 16 gage for 54" and larger and conforming to the requirements of "Standard Specification for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality", Grade C, ASTM Designation A-570.

Each completed cylinder, with joint rings welded to its ends, shall be subjected to a hydrostatic test by closing the ends at the joint rings; filling with water in contact with welds at all points; and raising the water pressure to produce a stress of 20,000 to 25,000 psi in the cylinder. While under pressure test, all welds shall be thoroughly inspected. If any leaks are found, they shall be repaired and the cylinder shall be retested. The finished cylinder, with joint rings attached, shall be watertight under the required test pressure. Welding shall be by an approved process and test welds shall be furnished from the work as required.

STEEL REINFORCEMENT

The wire used for circumferential reinforcement shall conform to the requirements of "Standard Specification for Hard-Drawn Steel Mechanical Spring Wire", ASTM Designation A-227 and "Standard Specification for Steel Wire, Hard-Drawn for Prestressing Concrete Pipe", ASTM Designation A-648.

CONCRETE

Cement shall fulfill the requirement of "Standard Specification for Portland Cement", ASTM Designation, C-150. Concrete aggregates shall be composed of hard durable particles, clean and free from loam or organic materials. Water used in mixing the concrete shall be clean and free from deleterious amounts of acids, alkalis or organic materials.

The concrete used in the manufacture of the pipe shall consist of cement, sand and crushed stone or crushed or uncrushed gravel accurately proportioned for density and strength. In no case shall the cement content be less than 564 lbs. (6 bags) per cubic yard in the finished product.

The concrete lining of the steel cylinder shall be placed by the centrifugal process or other approved method. The concrete placement method in conjunction with the curing procedure employed, shall produce concrete of the required strength of quality. The inner surface of centrifugated pipe may be finished either while it is still in the machine or by means of a honing operation after the concrete has set. When the placing of the concrete is completed, the lined cylinder shall be placed in position for curing.

The concrete shall have a minimum strength of 3000 psi at seven days and 4500 psi at 28 days as measured by 6" x 12" companion cylinders molded in accordance with the "Standard Method for Making and Curing Concrete Compression and Flexure Test Specimens in the Field", ASTM Designation C-31, and cured in the same manner and for the same duration as the pipe. To conform to the requirements of this section, the average of any ten consecutive strength tests of cylinders representing each type of concrete shall be equal to or greater than the specified strength and not more than 20% of the strength tests shall have values less than the specified strength.

CURING OF CONCRETE

Curing shall be by either steam or water. The use of water shall be limited to times when the temperature in the curing enclosure is continuously above 40°F. Adequate facilities and space shall be provided for proper curing.

Steam Curing—The cores shall be placed in the steam curing chamber or otherwise covered by a suitable enclosure that will allow proper circulation of steam. A delay period of from 1 to 4 hours shall be allowed before moist steam is admitted in contact with the cores. The temperature within the enclosure shall be gradually raised to at least 110°F and not more than 150°F for a period of at least 24 hours. The preset time shall be included in the 24 hour period. Curing by steam shall be continuous, except during a period sufficient to remove the forms or supporting rings.

The end rings shall not be removed until at least 6 hours after the beginning of steam curing. Following this minimum period, in lieu of further steam curing, the cores may be moved to the storage yard, where they shall be kept continuously moist by intermittent spraying for a period of at least 5 days.

Water Curing—The core shall be kept moist by water spraying for a period of 32 hours. The end rings shall not be removed from the core until at least 12 hours after beginning of curing. After being placed in the storage yard, the core shall be kept moist by intermittent sprinkling for a further period of three days.

CEMENT MORTAR COATING

The cement mortar coating shall be applied to the cores after they have been wrapped under tension with high tensile wire. The mortar used for this coating shall consist of one part of cement to not more than 3 parts of fine aggregate measured by volume. The mortar shall be placed on the pipe by a machine in which the mortar, previously mixed, is driven against the exterior surface of the core to produce a dense coating around the prestress wires. The thickness of coating, measured from the outer surface of the cylinder, shall not be less than that specified.

CURING OF MORTAR COATING

Steam Curing—The coated pipe shall be placed in the curing chamber as soon as practicable after placing the coating and shall be steam-cured as specified under Curing of Concrete for a period of at least 12 hours. The pipe shall be handled in such a manner as to avoid injury to the coating during transportation to and from the curing chamber.

Water Curing—As soon as the coating has set sufficiently, it shall be kept moist by continuous water spraying or by intermittent spraying and burlap and canvas covering for a period of at least 4 days.

CURVES AND FITTINGS

Curves of long radius may be formed by the deflection of each joint, by the use of pipe on which the spigot joint rings are placed on a bevel or by bevel adapters. Fittings shall be designed to provide the same strength as the adjacent pipes. Elbows, tees, reducers and wyes shall be of non-prestressed steel cylinder type construction. Branch connections or openings such as manholes, air valves and blowoffs may be incorporated in straight pipe and shall be suitably reinforced. Fittings shall be provided with joint rings corresponding to those on adjoining straight pipes. Special adapters shall be provided where required to connect to valves or pipes of other manufacturers.

NOTE—Pipe lines utilizing the type of pipe covered by the above specification are designed to meet a test with leakage not exceeding 25 gallons per inch of diameter per mile of pipe per 24 hours, at normal operating pressure.

Small cracks in the concrete which are not damaging should not be considered as cause for rejection.

The term "ASTM" shall mean the American Society for Testing and Materials. When specific ASTM specifications are cited, the designation shall be construed to refer to the latest revision.

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SPECIFICATIONS FOR PRESTRESSED CONCRETE EMBEDDED CYLINDER PIPE WITH RUBBER AND STEEL JOINTS

**Produced According to
AWWA Standard C-301-72**

TYPE OF PIPE

The pipe shall be of the type known as Prestressed Concrete Embedded Cylinder Pipe. It shall be reinforced with a welded steel cylinder with steel joint rings welded to its ends. The steel cylinder shall be lined with not less than 1" of concrete and the nominal core wall will be according to the table on the facing page. The core shall be wrapped with a high tensile strength wire under tension and coated with a dense covering of cement mortar or concrete. Each pipe shall be constructed with a self-centering expansion joint sealed with a rubber gasket and capable of caring for normal movement due to earth settlement and extremes of temperature.

DIMENSIONS

The dimensions of the straight pipe shall be in accordance with the table on the facing page.

Dimensions for larger diameters shall be submitted by the manufacturer for approval. Special pipe for bends, reducers, closure pieces and other fittings may be made in shorter lengths as required.

The pipe shall be round and true. The average internal diameter of the straight pipe shall not be less than the nominal diameter by more than 1/4" for sizes 36" or smaller; by more than 3/8" for sizes 42" and 48"; by more than 1/2" for sizes 54" to 78"; or by more than 3/4" for 84" or larger.

PIPE DESIGN

The diameter of wire used, its centerline spacing and the tension under which it is wound around the core shall be sufficient to produce the required prestress in the core. The elastic and inelastic deformations of the concrete and steel shall be taken into consideration. The gross wrapping stress in the high tensile wire shall not exceed 75% of the minimum ultimate tensile strength of the wire. The maximum centerline spacing shall be 1-1/2". Minimum centerline spacing of the wires shall be that which produces a clear distance between wires of 3/16". The minimum diameter of the wire used shall be No. 8 gage.

Steel sheets and steel wire of qualities other than those indicated below may be used, provided the design of the pipe is based upon the respective physical properties of the materials.

The core shall not be wrapped with the wire until the concrete has reached the specified seven day compressive strength. The initial compression induced in the concrete shall not exceed 55% of its compressive strength at the time of wrapping.

PIPE JOINTS

The joint shall be sealed by a rubber gasket in such a manner that it will remain tight under all conditions of service, including movement due to expansion, contraction and normal settlement. Each length of pipe shall be provided with bell and spigot ends formed by steel joint rings welded to the cylinder. The spigot ring shall be lined with concrete on its interior surface and the bell ring shall be covered with concrete on its exterior surface. Portions of the joint rings which will be exposed after the pipe is manufactured shall be protected from corrosion by an approved coating. The spigot ring shall have a groove for the purpose of receiving, holding and protecting the gasket. The joint surfaces shall be of such shape and dimensions that the joint will be self-centering when the pipe is laid so that the gasket will not be required to support the weight of the adjoining pipe.

Steel of flat section for bell rings 3/16" thick shall be used on pipe sizes up to and including 36" and shall conform to "Standard Specification for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality", Grade C, ASTM Designation A-570.

Steel plate for bell rings 1/4" or more in thickness and special shapes for spigot joint rings shall conform to "Standard Specifications for Carbon Steel Bars Subject to Mechanical Property Requirements", Grade 50, ASTM Designation A-306.

The gasket sealing the joint shall be made of a rubber having a texture to assure a watertight and permanent seal and shall be the product of a manufacturer having at least five years' experience in the manufacture of rubber gaskets for pipe joints. The gasket shall be a continuous ring, of suitable cross-section and of such size as to fill the groove on the spigot joint ring when the pipes are laid. The rubber gasket shall be the sole element depended upon to make the joint watertight and shall have smooth surfaces free from pitting, blisters, porosity and other imperfections. Each gasket shall be subjected to a stretch of 100% and examined for any defects while in the stretched condition. Cement mortar or plastic materials used to finish the joint shall not be depended upon for watertightness.

Synthetic isoprene gaskets shall comply with the following physical requirements:

Tensile strength, min. psi	3000
Elongation at rupture, min. percent	425
Compression set, max. percent	18
Accelerated aging	
Tensile strength retained, min. percent of original	85
Elongation retained, min. percent of original	80
Water absorption	
Volume and weight increase, max. percent	5
Durometer hardness, points	60±5

The physical properties of the gaskets shall be determined in accordance with the following methods:

Tensile Strength	"Tension Testing of Vulcanized Rubber", ASTM Designation D-412
Elongation	"Tension Testing of Vulcanized Rubber", ASTM Designation D-412
Compression Set	"Compression Set of Vulcanized Rubber", ASTM Designation D-395, Method B, age 22 hours at 70°C
Accelerated Aging	"Oven Test for Aging of Rubber", ASTM Designation D-573, age 96 hours at 70°C
Water Absorption	"Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids", ASTM Designation D-471, age 48 hours at 70°C
Durometer Hardness	"Indentation Hardness of Rubber and Plastics by Means of a Durometer", Type A, ASTM Designation D-2240

STEEL CYLINDER

The steel cylinder shall be made of hot rolled steel sheets not lighter than No. 18 gage for 24" thru 48" diameter pipe and 16 gage for 54" and above, both U.S. Standard and conforming to the requirements of "Standard Specification for Hot-Rolled Carbon Steel Sheets and Strip, Structural Quality", Grade C, ASTM Designation A-570.

Each completed cylinder, with joint rings welded to its ends, shall be subjected to a hydrostatic test by closing the ends at the joint rings; filling with water in contact with welds at all points; and raising the water pressure to produce a stress of 20,000 to 25,000 psi in the cylinder. While under pressure test, all welds shall be thoroughly inspected. If any leaks are found, they shall be repaired and the cylinder shall be retested. The finished cylinder, with joint rings attached, shall be watertight under the required test pressure. Welding shall be by an approved process and test welds shall be furnished from the work as required.

STEEL REINFORCEMENT

The wire used for prestressing shall conform to the requirements of "Standard Specification for Hard-Drawn Steel Mechanical Spring Wire", ASTM Designation A-227 and "Standard Specification for Steel Wire, Hard-Drawn for Prestressing Concrete Pipe", Designation A-648.

CONCRETE

Cement shall fulfill the requirements of "Standard Specification for Portland Cement", ASTM Designation C-150. Concrete aggregates shall be composed of hard durable particles, clean and free from loam or organic materials. Water used in mixing the concrete shall be clean and free from deleterious amounts of acids, alkalis or organic materials.

The concrete used in the manufacture of the pipe shall consist of cement, sand and crushed stone or crushed or uncrushed gravel accurately proportioned for maximum density and specified strength. In no case shall the cement content be less than 564 lbs. (6 bags) per cubic yard in the finished product.

The concrete shall be placed in steel molds so constructed that the inner and outer forms, joint rings and cylinder shall be held in circular and concentric positions. The molds shall be vibrated during the placing of each batch of concrete.

The concrete shall have a minimum strength of 3000 psi at seven days and 4500 psi at 28 days as measured by 6" x 12" companion cylinders molded in accordance with the "Standard Method for Making and Curing Concrete Compression and Flexure Test Specimens in the Field", ASTM Designation C-31, and cured in the same manner and for the same duration as the pipe. To conform to the requirements of this section, the average of any ten consecutive strength tests of cylinders representing each type of concrete shall be equal to or greater than the specified strength and not more than 20% of the strength tests shall have values less than the specified strength.

CURING OF CONCRETE

Curing shall be by either steam or water. The use of water shall be limited to times when the temperature in the curing enclosure is continuously above 40°F. Adequate facilities and space shall be provided for proper curing.

Steam Curing—The cores shall be placed in the steam curing chamber or otherwise covered by a suitable enclosure that will allow proper circulation of steam. A delay period of from 1 to 4 hours shall be allowed before moist steam is admitted in contact with the cores. The temperature within the enclosure shall be gradually raised to at least 110°F and not more than 150° for a period of at least 24 hours. The preset time shall be included in the 24 hour period. Curing by steam shall be continuous, except during a period sufficient to remove the forms or supporting rings.

The forms shall not be removed until at least 6 hours after the beginning of steam curing. Following this minimum period, in lieu of further steam curing, the cores may be "tipped" from their bases and removed to the storage yard, where they shall be kept continuously moist by intermittent spraying for a period of at least 5 days.

Water Curing—The core shall be kept moist by water spraying for a period of 32 hours. The forms shall not be removed from the core until at least 12 hours after beginning of curing. After being placed in the storage yard, the core shall be kept moist by intermittent sprinkling for a further period of three days.

PIPE COATING

The coating, either cement mortar or concrete, shall be applied to the cores after they have been wrapped under tension with high tensile wire.

CEMENT MORTAR COATING

The mortar used for this coating shall consist of one part of cement to not more than 3 parts of the fine aggregate measured by volume. The mortar shall be placed on the pipe by a machine in which the mortar, previously mixed, is driven against the exterior surface of the core to produce a dense coating around the prestress wires. The thickness of coating, measured from the outer surface of the core, shall not be less than that specified.

CONCRETE COATING

The concrete used for this coating shall be so proportioned that the cement content is no less than 658 lbs. (7 bags) per cubic yard. The concrete shall be placed in steel molds so constructed that the outer form and the core shall be held in circular and concentric positions. The molds shall be continously vibrated during the placing of each batch of concrete.

The thickness of coating shall not be less than 1".

CURING OF COATING

Steam Curing—The coated pipe shall be placed in the curing chamber as soon as practicable after placing the coating and shall be steam-cured as specified under Curing of Concrete for a period of at least 12 hours. The pipe shall be handled in such a manner as to avoid injury to the coating during transportation to and from the curing chamber.

Water Curing—As soon as the coating has set sufficiently, it shall be kept moist by continuous water spraying or by intermittent spraying and burlap and canvas covering for a period of at least 4 days.

CURVES AND FITTINGS

Curves of long radius may be formed by the deflection of each joint, by the use of pipe on which the spigot joint rings are placed on a bevel or by bevel adapters. Fittings shall be designed to provide the same strength as the adjacent pipes. Elbows, tees, reducers and wyes shall be of non-prestressed steel cylinder type construction. Branch connections or openings such as manholes, air valves and blowoffs may be incorporated in straight pipe and shall be suitably reinforced. Fittings shall be provided with joint rings corresponding to those on adjoining straight pipes. Special adapters shall be provided where required to connect to valves or pipes of other manufacturers.

NOTE—Pipe lines utilizing the type of pipe covered by the above specification are designed to meet a test with leakage not exceeding 25 gallons per inch of diameter per mile of pipe per 24 hours, at normal operating pressure.

Small cracks in the concrete which are not damaging should not be considered as cause for rejection.

The term "ASTM" shall mean the American Society for Testing and Materials. When specific ASTM specifications are cited, the designation shall be construed to refer to the latest revision.

Steel Fittings
Specification

Scope

This specification covers the design and manufacture of cement-mortar lined and coated steel fittings for closures, curves, bends, branches, manholes, outlets, connections for main line valves, and other pipeline appurtenances shown in the contract drawings or ordered by the purchaser. It is intended to complement specifications for various types of line pipe.

Except for cement-mortar lined and coated steel pipe, this specification does not cover modifications of line pipe such as affixing outlets to standard pipe sections. However, the combination or attachment to line pipe of fittings or elements of fittings made under this specification may be permitted.

General

Fittings shall consist of steel sheet or plate fabricated so that the finished product, after being lined and coated, shall have the required strength, shape and dimensions and shall have joints compatible with the line pipe or appurtenances.

Materials

1. Concrete and Cement Mortar

1.1 Cement
Portland cement shall conform to the current "Specification for Portland Cement" (ASTM Designation: C150), Type I or Type II, unless otherwise specified. Cement shall be stored in a dry, well ventilated location protected from the weather.

1.2 Aggregates
Aggregates shall conform to the current "Specification for Concrete Aggregates" (ASTM Designation: C33), except that grading requirements therein shall not apply.

1.3 Water
Water used in mixing and curing concrete and cement mortar shall be clean and free from deleterious amounts of oil, acid, alkalies, and organic materials.

1.4 Admixtures
The use of admixtures containing chlorides is prohibited.

1.5 Concrete for Centrifugally Placed Linings
Concrete used to line fittings shall consist of portland cement, fine aggregate, coarse aggregate and water. The minimum cement content shall be 7 sacks per cubic yard of concrete.

1.6 Cement Mortar for Lining and Coating
Cement mortar shall consist of one part cement to not more than three parts of fine aggregate by weight. For centrifugally placed linings and for hand troweling, only enough water to obtain the proper consistency of the mortar shall be used, and the total free water content of the mixture shall not exceed 7½ gallons per sack of cement. For mechanically applied coatings, the water content of the mortar shall be not less than 6 percent of the total dry weight of cement and aggregate. For pneumatically applied mortar, the amount of water added at the nozzle shall be adjusted so that the in-place material is adequately compacted and free of sags.

2. Steel for Reinforcement

2.1 Steel Sheet or Plate
Steel sheets shall conform to the current "Specification for Hot Rolled Carbon Steel Sheets and Strip, Structural Quality" (ASTM Designation: A570), Grade B or C. Steel plates shall conform to the current "Specification for Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality" (ASTM Designation: A283), Grade C or D or "Specification for Structural Steel" (ASTM Designation: A36).

Note: ASTM A570 or ASTM A283 steels with other yield strengths may be specified provided the design circumferential stress conforms with Section 4.

2.2 Steel Bar or Wire for Reinforcement
Steel bar to be wrapped on the cylinder shall be plain round bar conforming to the current "Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement" (ASTM Designation: A615), Grade 40, except that ASTM A615 bar smaller than No. 3 shall meet the applicable requirements for No. 3 bar. Steel wire to be embedded in the coating shall conform to the current "Specification for Cold-Drawn Steel Wire for Concrete Reinforcement" (ASTM Designation: A82).

2.3 Steel for Joint Rings
Steel for bell and spigot joint rings shall conform to the current AISI Grade Designation 1012 or "Specification for Merchant Quality Hot-Rolled Carbon Steel Bars" (ASTM Designation: A575) Grade Designation 1012 for bell rings and "Specification for Special Quality Hot-Rolled Carbon Steel Bars" (ASTM Designation: A576), Grade Designation 1012 for spigot rings.

2.4 Welded Wire Fabric
Welded wire fabric shall conform to the current "Specification for Welded Steel Wire Fabric for Concrete Reinforcement" (ASTM Designation: A185).

2.5 Steel Castings and Forgings
Steel castings shall conform to the current "Specification for Mild- to Medium-Strength Carbon Steel Castings for General Application" (ASTM Designation: A27), Grade 70-36, Normalized. Forgings shall comply with the current "Specification for Forged or Rolled Steel Pipe Flanges, Forged Fittings, and Valves and Parts for General Services" (ASTM Designation: A181), Grade I or II.

2.6 Flanges
Flanges for service ratings not greater than 275 psi shall comply with the cur-

rent specifications for "Steel Pipe Flanges" (AWWA Standard: C207). Flanges for service ratings greater than 275 psi shall comply with the current specifications for "Steel Pipe Flanges and Flanged Fittings" (ANSI Standard: B16.5). Flanges 10 inches and smaller may be slip-on welding flanges conforming to ANSI B16.5.

3. Rubber for Gaskets
Rubber gaskets for joints shall meet the requirements specified for pipe.

Design

4. Sheet or Plate Cylinders
At the design pressure, the average circumferential stress in the steel or plate shall not exceed 15,000 psi nor 50 percent of the specified minimum yield strength of the sheet or plate used in the cylinder.

5. Bends or Elbows
Unless otherwise indicated, the minimum centerline radius of an elbow shall be as follows:

Fitting Diameter Range	Minimum Centerline Radius
up to 51 in.	2.5 times inside diameter
51 – 60 in.	10 feet
over 60 in.	2 times inside diameter

The maximum deflection at mitered girth seams shall be 22.5 degrees.

6. Outlet, Tee and Wye Branches
Type of reinforcement required for outlet, tee or wye branches on fittings shall depend on the ratio of the length of run intercepted by the branch to the inside diameter of the run as shown in the following table:

Run Diameter Range	Maximum Ratio		
	Collars	Wrappers	Crotch Plates
up to 24 in.	.6	1.0	No Limit
24 in. and over	.8	.8	No Limit

$$\text{Where Ratio} = \frac{D_b}{D_r \times \sin\theta}$$

and

D_b = Nominal inside diameter of outlet, tee or wye branch, inches
D_r = nominal inside diameter of run, inches
θ = angle between the longitudinal axis of the run and branch

At the option of the manufacturer, wrappers may be used in place of collars, and crotch plates may be used in place of collars or wrappers. Outlets 3 inches in diameter or smaller may not require reinforcement.

6.1 Sizing of Collars and Wrappers
The shoulder width "W" of collars or wrappers from the inside surface of the branch cylinder to the outside edge of the collar or wrapper measured on the surface of the run cylinder shall not be less than 1/3 nor more than 1/2 the length of run intercepted by the inside diameter of the branch cylinder. The thickness of the collar or wrapper shall be not less than "T" as determined by:

$$T = \frac{P_w \times ID_r \times ID_b \times (2-\sin\theta)}{4 \times f_s \times W \times \sin\theta}$$

where

P_w = design pressure, psi
ID_r = inside diameter of run cylinder, inches
ID_b = inside diameter of branch cylinder, inches
f_s = design stress, psi (Section 4)
θ = angle between the longitudinal axis of run and branch, degrees
T = thickness of wrapper, inches
W = shoulder width of wrapper, inches

6.2 Crotch Plates
Design of fittings using crotch plates shall be based on the paper, "Design of Wye Branches for Steel Pipe," by Swanson, Chapton, Wilkinson, King and Nelson and published in the June, 1955 issue of the "Journal of the American Water Works Association."

7. Rubber Gasket Joints
At the option of the manufacturer, bells and spigots for rubber gasket joints to line pipe shall be provided by welding preformed steel rings to the cylinder with or without spacer rings, or by swaging or rolling the ends of the steel cylinder to the required bell or spigot shape. The nominal thickness of a preformed bell ring shall be not less than the thickness of the steel cylinder to which it is attached. Bells and spigots for rubber gasket joints shall have the same nominal diameter as joints in the line pipe. Joint rings on completed fittings shall have the following circumferential tolerances:

Joint Ring	Tolerance on Taped Circumference	
	Minus	Plus
Bell	0	0.10 in.
Spigot	0.10 in.	0

Longitudinal seams and girth seams shall be butt-welded except that girth seams between fittings and standard pipe sections may be lap welded.

The sequence of welding and the fitting manufacturer's welding procedures are subject to approval by the purchaser.

All welding shall be done by skilled welders or welding operators who have had experience in the methods and materials to be used.

8.3 Weld Inspection and Testing
All welds shall be visually inspected in process and upon completion for compliance with the approved drawings. Final testing shall be in accordance with Section 15 of this specification.

The inspector may request, at any time he believes satisfactory welding is not being performed, weld tests made on samples welded in the same manner as the welding being performed on the job. The weld tests and the results shall conform to the provisions of Section 3.4.6 of the current specification for "Steel Water Pipe 6 Inches and Larger" (AWWA Standard: C200). If any specimen so tested fails to meet the requirements, retests of two additional specimens from the same welding work shall be made, each of which shall meet the requirements specified.

9. Preformed Joint Rings
The joint ring stock shall be rolled and butt welded to form round steel rings. Resistance or electric arc welding may be used. Welds on gasket contact surfaces shall be ground smooth and flush with the adjacent surface. The steel joint rings shall be sized by expansion beyond their elastic limits. Steel joint rings shall be attached to fittings by electric arc welding. The minimum throat dimension of the joint ring fillet weld shall be 0.12 inch.

10. Welded Wire Fabric Reinforcing
Crimped 2-inch x 4-inch x No. 13 gauge welded wire fabric shall be applied to exterior steel surfaces which are to be cement-mortar coated. Plain 2-inch x 4-inch x No. 13 gauge welded wire fabric shall be applied to interior steel surfaces of fittings 27 inches in diameter and larger which are to be cement-mortar lined. Wires at 2-inch spacing shall extend circumferentially around the fitting with the ends overlapped 4 inches. Longitudinal splices of fabric shall be staggered. Wire fabric reinforcing of concrete or cement-mortar linings will not be required for centrifugally placed or in-place linings.

11. Concrete or Cement-Mortar Lining
Concrete or cement mortar for lining fittings shall meet the requirements of Section 1.5 or 1.6, and shall be applied centrifugally, pneumatically, or by hand troweling. Temperature of the mix shall be not less than 40°F at the time of placement. Lining thickness measured from the inside surface of the cylinder shall not vary more than 25 percent from the nominal thickness specified on the detailed drawings approved by the engineer. When heavy plate is required, the inside diameter of fittings may be reduced to meet this requirement.

11.1 Centrifugal Application
Aggregate and cement for centrifugally placed lining shall be batched by weighing. All water used in the mix shall be metered or weighed and allowance shall be made for free moisture present in the sand. All materials shall be mixed for not less than 1 minute in pan, turbine, or paddle type mixers. No water may be added once the mix has been discharged from the mixer.

11.2 Pneumatic Application
Aggregate and cement for pneumatically applied cement mortar shall be batched by weighing, or by volume if periodic weight checks are made. Water shall be added to the mix by means of a manually operated water injection system at the discharge nozzle. Segregated materials shall not be incorporated into the work. Cement mortar shall be placed by an experienced nozzleman using equipment which provides a steady flow of material.

12. Cement-Mortar Coating
Cement mortar for coating fittings shall meet the requirements of Section 1.6 and shall be applied mechanically, pneumatically or by hand. The minimum thickness of the coating over the steel sheet or plate shall be 1 inch. Temperature of the mortar mix shall be not less than 40°F at the time of placement.

12.1 Mechanical Application
Fine aggregate and cement for mechanically applied cement-mortar coating shall be batched by weighing, and all water used in the mix shall be metered or weighed. All materials shall be mixed for not less than 1 minute in pan, turbine, or paddle type mixers. No water may be added once the mortar has been discharged from the mixer. Rebound not to exceed one-fourth of the total mix weight may be used but the resulting mix proportions shall be not leaner than 1:3. Rebound not used within 1 hour shall be discarded. The cement mortar shall be mechanically impelled against the fitting to form a coating of the required thickness.

12.2 Pneumatic Application
Pneumatic application of cement mortar shall be in accordance with Section 11.2.

13. Curing
Linings and coatings shall be steam cured, water cured or membrane cured at the option of the manufacturer except that water cure or membrane cure shall be used only if the minimum ambient temperature exceeds 40°F, and except that membrane cure shall not be used for centrifugally applied linings. Water cure and steam cure may be used interchangeably on a time ratio basis of 4 hours of water cure to 1 hour of steam cure. After

completing at least one-sixth of the minimum applicable cure period, the manufacturer may defer the remainder of the required cure and perform further work on the fitting.

13.1 Steam Cure
Steam cure may begin immediately after the lining or coating operation, but the steam shall not raise the ambient temperature above 90°F within 3 hours or until the concrete or cement mortar has taken its initial set, whichever occurs first. The ambient vapor shall then be maintained at a temperature between 110°F and 150°F for a minimum period of 36 hours.

13.2 Water Cure
Water cure shall begin as soon as the mortar can be sprinkled without damage. Cement mortar shall be kept moist by intermittent sprinkling for a period of at least 6 days before being moved to the jobsite. At the option of the manufacturer, centrifugally applied linings may be cured by covering fitting ends with plastic or wet burlap for the same period in lieu of sprinkling.

13.3 Membrane Cure
Linings or coatings shall be membrane cured by the prompt application of a clear- or white-pigmented sealing compound conforming to the current "Specification for Liquid Membrane-Forming Compounds for Curing Concrete" (ASTM Designation: C309). Fittings shall not be shipped for a minimum period of at least 6 days following application of sealing compound.

14. Coating of Joint Rings
Exposed steel surfaces of joint rings shall be painted with one coat of Amercoat No. 191 or approved equal.

Testing

15. Testing of Fittings
Welded seams in steel cylinders for short-radius bends and fittings shall be tested either by the air-soap method using air at a pressure of 5 psi or by the dye penetrant method at the option of the manufacturer. However, if the fitting is fabricated from cylinders which have been previously hydrostatically tested, no further test will be required on seams so tested. Defects revealed by any of the alternate test methods shall be repaired by welding and the fitting retested until all defects have been eliminated.

Marking, Handling and Shipment

16. Marking
Each fitting shall have plainly marked inside near one end the design pressure and the date coated, and shall be sufficiently identified to show its proper location in the pipeline by reference to layout drawings or schedules. Mitered ends shall be marked to show degree of bevel and the point of maximum pipe length at the spigot end.

17. Handling and Shipment
Fittings shall be handled carefully, and blocking and hold-downs used during shipment shall prevent movement or shifting. Leading ends of fittings on trucks or rail cars shall be bulkheaded or covered to prevent excessive drying of the linings.

Important Note

Pipe Products are engineered and manufactured to perform the functions for which they are recommended in our literature. Our recommendations are based on sound engineering principles and hundreds of successful installations; nevertheless, our products must be properly installed and used in accordance with good engineering judgment and practice.

The information offered herein is to be used as a guide and is not to be taken as a warranty or representation for which Ameron assumes any legal responsibility. There is no assurance—specific or implied—that the use of this technical information in designs and specifications will insure a successful job. It is offered solely for your review and consideration.

THREE EDGE BEARING TESTS

Designation: C 497 – 75

Standard Methods of Testing
CONCRETE PIPE OR TILE[1]

This Standard is issued under the fixed designation C 497; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 These methods cover testing of concrete pipe and tile. The tests described are used in production testing and acceptance testing to evaluate the properties provided for in the specifications.

1.2 The tests appear in the following order:

	Section
External Load Crushing Strength	3 to 7
Core Strength	8 to 12
Absorption	13 to 16
Hydrostatic	17
Permeability	18

1.3 The test specimens shall not have been exposed to a temperature below 40°F (4°C) for the 24 h immediately preceding the test and shall be free from all visible moisture.

1.4 If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, it may be discarded and another specimen taken.

1.5 Specimens shall be selected in accordance with the specifications for the type of pipe or tile being tested.

2. Applicable Documents

2.1 *ASTM Standards:*

C 39 Test for Compressive Strength of Cylindrical Concrete Specimens[2]

C 42 Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[2]

C 617 Capping Cylindrical Concrete Specimens[2]

E 4 Verification of Testing Machines[2]

EXTERNAL LOAD CRUSHING STRENGTH TEST

3. Summary of Method

3.1 The test specimen shall be tested in a machine so designed that a crushing force may be exerted in a true vertical plane through one diameter and extending the full length of the wall of the specimen.

4. Apparatus

4.1 In making the test, any mechanical or hand-powered device may be used in which the head moves at such a speed that the load is applied at a uniform rate of not less than 500 nor more than 2500 lbf/linear ft of pipe per minute (not less than 7.3 nor more than 36.5 kN/linear m of pipe per minute).

4.2 The testing machine shall be substantial and rigid throughout, so that the distribution of the load will not be affected appreciably by the deformation or yielding of any part.

4.3 The three-edge-bearing method of loading shall be used. The test specimen shall be supported on two parallel longitudinal strips extending the full length of the barrel, and the load applied through a top bearing beam also extending the full length of the barrel (Figs. 1, 2, 3, and 4).

4.4 The lower bearings shall consist of hardwood or hard rubber strips. Wooden strips shall be straight, have a cross section of not less than 2 in. (51 mm) in width and not less than 1 in. (25 mm) nor more than 1½ in. (38 mm) in height and shall have the top inside corners rounded to a radius of ½ in. (13 mm). Hard rubber strips shall have a durometer hardness of not less than 45 nor more than 60. They shall be rectangular in cross section, having a width of not less than 2 in., a thickness of not less than 1 in. nor more

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[1] These methods are under the jurisdiction of ASTM Committee C-13 on Concrete Pipe and are the direct responsibility of Subcommittee C13.09 on Methods of Test.

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[2] *Annual Book of ASTM Standards*, Part 14.

than 1½ in., and shall have the top inside corner rounded to a radius of ½ in.

4.5 The bottom bearing strips shall be fastened to a wooden or steel beam or directly to a concrete base, any of which shall provide sufficient rigidity to permit application of maximum load without deflection greater than $\frac{1}{720}$ of the specimen length. The interior vertical sides of the strips shall be parallel and spaced a distance apart of not more than 1 in./ft (0.08 mm/mm) of specimen diameter, but in no case less than 1 in. (25 mm). The bearing faces of the bottom strips shall not vary from a straight line vertically or horizontally by more than $\frac{1}{32}$ in./ft (0.003 mm/mm) of length under no load.

4.6 The upper bearing shall be a rigid hardwood beam with or without an attached hard rubber strip. The wood block shall be sound, free of knots, and straight and true from end to end. It shall be fastened to a steel or wood-faced steel beam of such dimensions that deflections under maximum load will not be greater than $\frac{1}{720}$ of the specimen length. The bearing face of the top bearing block shall not deviate from a straight line by more than $\frac{1}{32}$ in./ft (0.003 mm/mm) of length. When a hard rubber strip is used on the bearing face it shall have a durometer hardness of not less than 45 nor more than 60, and shall have a width of not less than 2 in. (51 mm) and a thickness of not less than 1 in. (25 mm) nor more than 1½ in. (38 mm) and shall be secured to a wood block meeting the above requirements.

4.7 If mutually agreed upon by the manufacturer and the purchaser prior to the test, before the specimen is placed, a fillet of plaster of paris not exceeding 1 in. (25 mm) in thickness may be cast on the surface of the upper and lower bearings. The width of the fillet cap, top or bottom, shall be not more than 1 in./ft (0.08 mm/mm) of the specimen diameter, but in no case less than 1 in.

4.8 The equipment shall be so designed that the load can be distributed about the center of the over-all length of the pipe (Figs. 1, 2, 3, and 4). At the option of the manufacturer, the center of the load may be applied at any point of the over-all length of the pipe. The load may be applied either at a single point or at multiple points dependent on the length of pipe or tile being tested and the rigidity of the test frame. Multiple points of load application to the top bearing will permit use of lighter beams without appreciable deflection.

5. Calibration

5.1 The loading device shall be one which shall provide an accuracy of ±2 % at the specified test loads. A calibration curve may be used. The machines used for performing the three-edge-bearing tests shall be verified in accordance with Methods E 4.

6. Procedure

6.1 Place the specimen on the two bottom bearing strips in such a manner that the pipe or tile rests firmly and with the most uniform possible bearing on each strip for the full length of the wall.

6.2 Mark the two ends of the specimen at a point midway between the bearing strips and then establish the diametrically opposite point on each end.

6.3 Place the top bearing beam so that it contacts the two ends of the specimen at these marks. After placing the specimen in the machine on the bottom strips align the top bearing symmetrically in the testing machine. Apply the load at the rate indicated in 4.1 until either the formation of a 0.01-in. (0.25-mm) crack width or an ultimate strength load, as may be specified, is reached. If both the 0.01-in. crack and ultimate load are required, the specified rate of loading need not be maintained after the load at 0.01-in. crack has been determined.

6.4 The 0.01-in. (0.25-mm) crack load is the maximum load applied to the pipe before a crack having a width of 0.01 in. measured at close intervals, occurs throughout a length of 1 ft (305 mm) or more. Consider the crack 0.01 in. (0.25 mm) in width when the point of the measuring gage will, without forcing, penetrate $\frac{1}{16}$ in. (1.6 mm) at close intervals throughout the specified distance of 1 ft. Measure the width of the crack by means of a gage made from a leaf 0.01 in. in thickness (as in a set of standard machinist gages), ground to a point of $\frac{1}{16}$ in. in width with corners rounded and with a taper of ¼ in./in. (0.25 mm/mm) as shown in Fig. 5. The ultimate load is reached when the pipe will sustain no greater load.

7. Calculation

7.1 The crushing strength in pounds per linear foot (or kilonewtons per linear metre) shall be calculated by dividing the total load on the specimen by the laying length, *L*, as shown in Figs. 1, 2, 3, and 4. For tongue and groove pipe, the laying length, *L*, shall include either the length of the tongue or the length of the groove, whichever is the longer. In most machines the total load will include the dead load of the top bearing plus the load applied by the loading apparatus.

CORE STRENGTH TEST

8. Summary of Method

8.1 The compressive strength of the concrete in the pipe may be determined by making crushing tests of cores cut from the pipe.

9. Apparatus

9.1 A core drill shall be used for securing cylindrical core specimens from the wall of the pipe; a shot drill or a diamond drill may be used.

10. Test Specimens

10.1 A core specimen for the determination of compressive strength shall have a diameter at least three times the maximum size of the coarse aggregate used in the concrete. If cores are cut from the wall of the pipe and tested, the length to diameter ratio shall lie between one and two after the curved surfaces have been removed from the cut core.

10.2 *Moisture Conditioning*—Unless the agency for which the testing is being done directs otherwise, the core test specimens shall be submerged in lime-saturated water in accordance with the provisions of Method C 42.

NOTE—Length-diameter correction factors for dry concrete appear to depart considerably from those applicable to soaked concrete, but have not been firmly established; therefore, when cores are to be tested dry, only those with a length-diameter ratio of 2 to 1 shall be used. If such cores are not available, moisture conditioning shall be mandatory.

11. Procedure

11.1 *End Preparation and Capping*—Core specimens to be tested in compression shall have ends that are essentially smooth and perpendicular to the axis and of the same diameter as the body of the specimen. Before making the compression test, cap the ends of the specimen in order to meet the requirements of Method C 617.

11.2 *Measurement*—Prior to testing, measure the length of the capped specimen to the nearest 0.1 in. (2.5 mm) and determine its average diameter to the nearest 0.1 in. from two measurements taken at right angles near the center of the length.

11.3 Test specimens as prescribed in Section 4 of Method C 39.

12. Calculation and Report

12.1 Calculate the compressive strength of each specimen in pounds-force per square inch (or kilonewtons per square metre) based on the average diameter of the specimen. If the ratio of length to diameter is less than two, make allowance for the ratio of length to diameter by multiplying the compressive strength by the applicable correction factor given in the following table (determine values not given in the table by interpolation):

Ratio Length of Cylinder to Diameter, *l/d*	Strength Correction Factor
1.75	0[illegible]
1.50	0.9[illegible]
1.25	0.94
1.10	0.9[illegible]
1.00	0.[illegible]

ABSORPTION TEST

13. Test Specimens

13.1 *Method A Specimens*—Method A absorption test specimens shall be in accordance with the requirements of the applicable pipe specification and shall be used for the absorption procedure that requires 5 h for boiling and a natural water cooling period of 14 to 24 h.

13.2 *Method B Specimens*—Method B absorption test specimens shall consist of three 1½-in. diameter cores as taken from the two ends and the center area of each tile, pipe, or section.

14. Procedure for Boiling Absorption Test

14.1 *Drying Specimens*—Dry specimens in a ventilated mechanical convection oven at a temperature of 221 to 239°F (105 to 115°C).

14.1.1 *Method A*—Dry specimens until two successive weighings at intervals of not less than 6 h show an increment of loss not greater than 0.10 % of the last oven-dry mass of the specimen. Dry specimens with a wall thickness of 1.5 in. (38 mm) or less for a minimum of 24 h; dry specimens with a wall thickness of 1.5 to 3 in. (38 to 76 mm) for a minimum of 72 h. Use the last 6 h of the minimum drying time to determine whether or not the sample had obtained the proper dried mass.

14.1.2 *Method B*—Dry specimens for a minimum of 24 h.

14.2 *Weighing Dried Specimens*—Weigh the oven-dried specimens immediately upon removal from the oven where the drying temperature is 221 to 239°F (105 to 115°C).

14.3 *Immersion and Boiling:*

14.3.1 *Method A Specimen*—Within 24 h, carefully place the dried specimen that has been weighed, in a suitable receptacle that contains clean water at a temperature of 50 to 75°F (10 to 24°C). Use distilled water, rain water, or tap water that is known to have no effect on test results. Heat the water to boiling in not less than 1 h and not more than 2 h. Do not apply live steam to the water to shorten the preboil period until 1 h of heating by gas or electricity has been completed. Continue the boiling for 5 h. At the end of the 5-h boiling period, turn off the heat, and allow the specimen to cool in the water to room temperature by natural loss of heat for not less than 14 h nor more than 24 h.

14.3.2 *Method B Specimen*—Within 24 h, carefully place the dried specimen that has been weighed, in a suitable receptacle that contains clean water at a temperature of 50 to 75°F (10 to 24°C). Use distilled water, rain water, or tap water that is known to have no effect on test results. Heat the water to boiling in not less than 1 h and not more than 2 h. Do not apply live steam to the water to shorten the preboil periods until 1 h of heating by gas or electricity has been completed. Continue the boiling for 3 h. At the end of the 3-h boiling period, turn off the heat and cool the specimen for a period of 3 h by running cold tap water into the boiler, or by placing the specimen in a separate container of water. The temperature of the cooling water shall not exceed 65°F (16°C).

14.4 *Reweighing Wet Specimens*—Remove the water-cooled specimens from the water, place on an open drain rack, and allow to drain for 1 min. Remove the remaining superficial water by quickly blotting the specimen with a dry absorbent cloth or paper. Weigh the specimen immediately following blotting.

14.5 *Scale Sensitivity*—Weigh specimens weighing less than 1 kg to an accuracy of 0.10 % of the specimen mass. Weigh specimens weighing more than 1 kg to an accuracy of 1 g.

15. Calculation and Report

15.1 *Method A Specimen*—Take the increase in mass of the boiled specimen over its dry mass as the absorption of the specimen, and express it as a percentage of the dry mass. Report the results separately for each specimen.

15.2 *Method B Specimen*—Take the increase in mass of the boiled specimen over its dry mass as the absorption of the specimen, and express it as a percentage of the dry mass. Report the result as an average of the three 1½-in. diameter cores as taken from one tile or pipe. The absorption, as calculated by the Method B procedure, shall be considered satisfactory when its value does not exceed a value that is 0.5 % less than the absorption designated in the Method A procedure. When the absorption, as computed by the Method B procedure, does not meet the specified requirement, the producer may perform a retest using Method A.

16. Procedure for 10-Min Soaking Absorption Test

16.1 Test specimens for the determination of the 10-min water soaking absorption may be the same as are later used for the 5-h boiling absorption test. After drying and weighing as specified in 14.1 and 14.2, immerse the specimens in clear water for 10 min at room temperature. Then remove the specimens and weigh in accordance with 14.4, calculate the percentage absorption, and report in accordance with the provisions described in Section 15.

HYDROSTATIC TEST

17. Procedure

17.1 The equipment for making the test shall be such that the specimen under test can be filled with water to the exclusion of air and subjected to the required hydrostatic pressure without there being enough leakage from the ends of the pipe to interfere with the test, and such that no appreciable circumferential compression is placed on the outside of the specimen wall.

17.2 Do not test when the temperature of the specimen, the air around the specimen, or the water within the specimen is below 33°F (1°C).

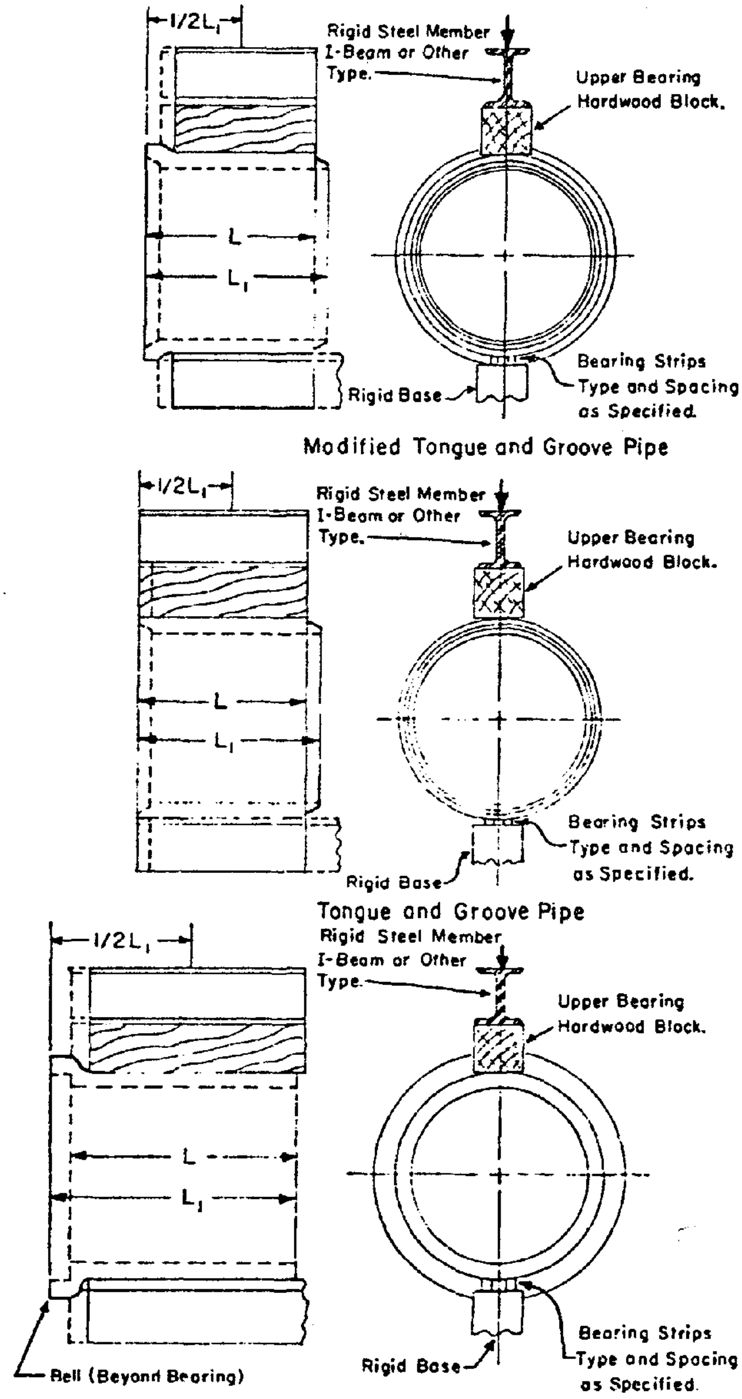
17.3 Connect a standardized pressure gage close to the specimen, and bring the water pressure up to 10 psi (69 kPa) in about 1 min, and hold at this pressure for 10 min.

17.4 After holding the water pressure at 10 psi (69 kPa) for 10 min, increase it at a uniform rate to the pressure specified.

PERMEABILITY TEST

18. Procedure

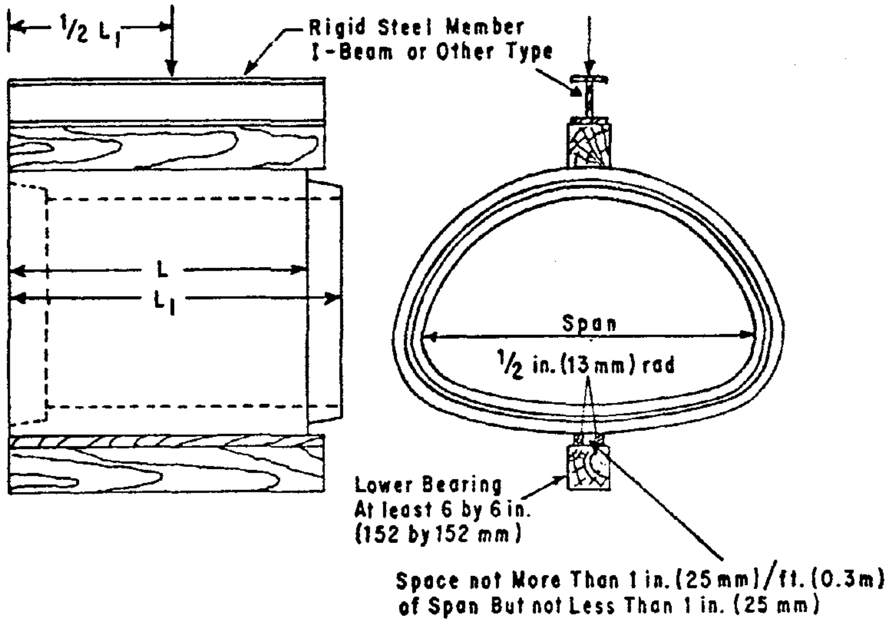
18.1 Perform tests by placing a section of pipe, with the spigot end down on a soft rubber mat or its equivalent, weighted if necessary, and kept filled with water to a level of the base of the socket during the test period. Make the initial inspection approximately 15 min after the test has begun. If the pipe shows moist or damp spots on the outer surface of the pipe at that time, continue the tests for a period not to exceed 24 h at the option of the manufacturer. Examine the pipe during the extended period for existence of moist or damp spots.



NOTE 1—The figures illustrate a method of applying the load to the pipe.

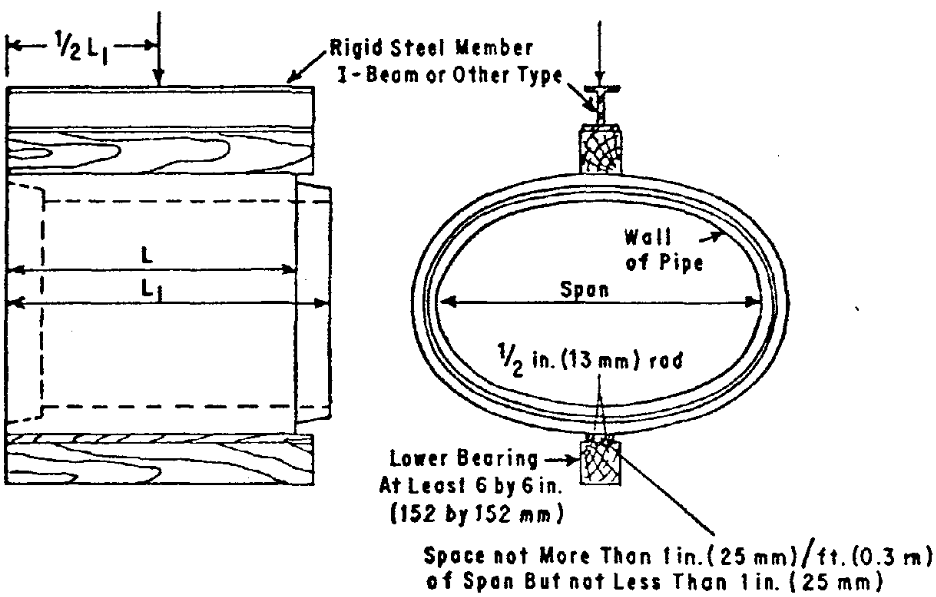
NOTE 2—At the option of the manufacturer the support and bearing beams may be varied as indicated by the dotted lines.

FIG. 1 Three-Edge Bearings.



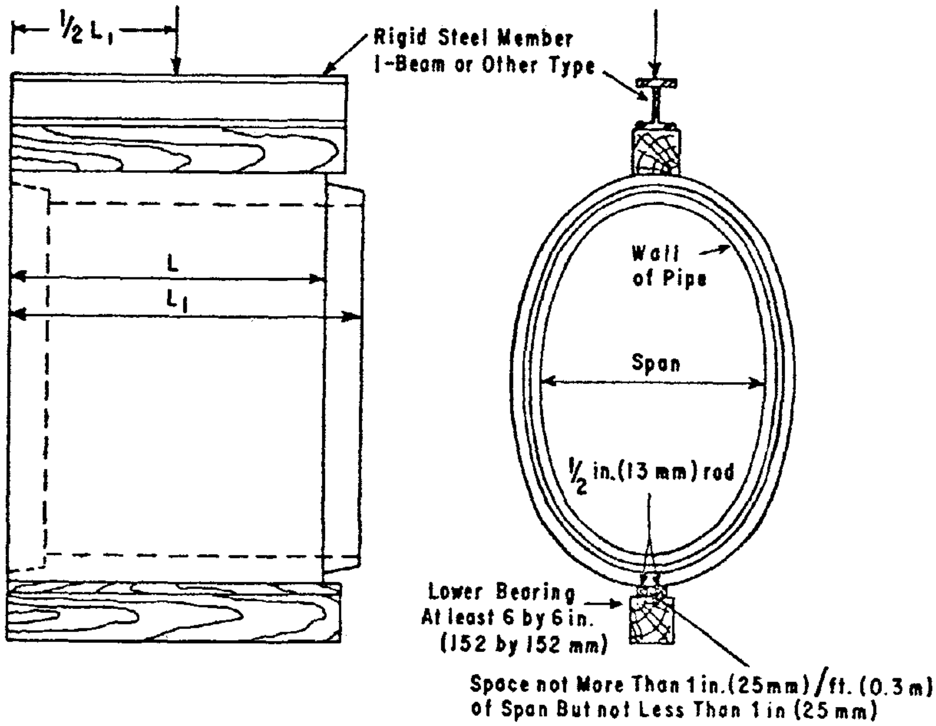
NOTE 1—The figure illustrates a method of applying the load to the pipe.
NOTE 2—At the option of the manufacturer, the support and bearing beams may be varied as indicated by the dotted lines.

FIG. 2 Three-Edge-Bearing Test, Arch Pipe.



NOTE 1—The figure illustrates a method of applying the load to the pipe.
NOTE 2—At the option of the manufacturer, the support and bearing beams may be varied as indicated by the dotted lines.

FIG. 3 Three-Edge-Bearing Test, Horizontal Elliptical Pipe.



NOTE 1—The figure illustrates a method of applying the load to the pipe.
NOTE 2—At the option of the manufacturer, the support and bearing beams may be varied as indicated by the dotted lines.

FIG. 4 Three-Edge-Bearing Test, Vertical Elliptical Pipe.

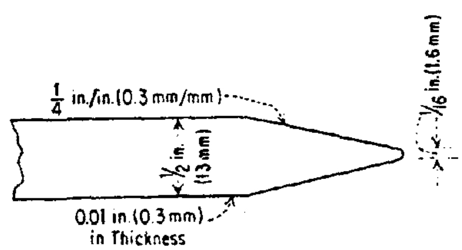


FIG. 5 Gage Leaf for Measuring Cracks.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, is entirely their own responsibility.

BELL AND SPIGOT RINGS

(Alternate to ASTM A 306)

Designation: A 283 – 74

American National Standard G24.2
American National Standards Institute

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia, Pa., 19103

Standard Specification for
LOW AND INTERMEDIATE TENSILE STRENGTH CARBON STEEL PLATES OF STRUCTURAL QUALITY[1]

This Standard is issued under the fixed designation A 283; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification[2] covers four grades of carbon steel plates of structural quality for general application.

NOTE—The values stated in U.S. customary units are to be regarded as the standard.

2. General Requirements for Delivery

2.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of ASTM Specification A 6, for General Requirements for Delivery of Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use.[3]

3. Process

3.1 The steel shall be made by one or more of the following processes: open-hearth, basic-oxygen, or electric-furnace.

4. Chemical Requirements

4.1 The heat analysis shall conform to the requirements prescribed in Table 1.

4.2 The steel shall conform on product analysis to the requirements prescribed in Table 1, subject to the product analysis tolerances in Specification A 6.

5. Tensile Requirements

5.1 Material as represented by the test specimens shall conform to the requirements as to tensile properties prescribed in Table 2.

5.2 For material under 5⁄16 in. (1.58 mm) in thickness a deduction from the percentage of elongation in 8 in. or 200 mm specified in Table 2 of 1.25 percentage points shall be made for each decrease of 1⁄32 in. (0.79 mm) of the specified thickness below 5⁄16 in.

6. Bend Test Requirements

6.1 The bend test specimens shall stand being bent cold through 180 deg without cracking on the outside of the bent portion, to an inside diameter which shall have a relation to the thickness of the specimen as prescribed in Table 3.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.02 on Structural Steel for Bridges, Buildings, Rolling Stock, and Ships.

Current edition approved July 29, 1974. Published September 1974. Originally published as A 283 – 46 T. Last previous edition A 283 – 70a.

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-283 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Part 4.

TABLE 1 Chemical Requirements

	Heat Analysis, %
Phosphorus, max	0.04
Sulfur, max	0.05
Copper, when copper steel is specified, min	0.20

TABLE 2 Tensile Requirements

	Grade A	Grade B	Grade C	Grade D
Tensile strength, psi (MPa)	45 000 (310) to 55 000 (380)	50 000 (345) to 60 000 (415)	55 000 (380) to 65 000 (450)	60 000 (415) to 72 000 (495)[a]
Yield point, min, psi (MPa)	24 000 (165)	27 000 (185)	30 000 (205)	33 000 (230)
Elongation in 8 in. or 200 mm, min, %[b, c]	27	25	22	20
Elongation in 2 in. or 50 mm, min, %[c]	30	28	25	23

[a] The upper limit of 72 000 psi (495 MPa) shall be increased by 3000 psi (20 MPa) for material over 1½ in. (38 mm) in thickness.
[b] See Section 5.2.
[c] Elongation not required to be determined for floor plate.

TABLE 3 Bend Test Requirements

Thickness of Material, in. (mm)	Ratio of Inside Diameter of Bend to Thickness of Specimen[a]			
	Grade A	Grade B	Grade C	Grade D
¾ (19) and under	flat on itself	flat on itself	flat on itself	½
Over ¾ to 1 (19 to 25), incl	flat on itself	flat on itself	½	1
Over 1 to 1½ (25 to 38), incl	½	¾	1	1½
Over 1½ to 2 (38 to 51), incl	1	1½	2	2½
Over 2 to 3 (51 to 76), incl	1½	2	2½	3
Over 3 to 4 (76 to 102), incl	2	2½	3	3½
Over 4 (102)	2½	3	3½	4

[a] The above ratios apply to the bending performance of a test specimen only. This specimen is always taken in the longitudinal direction and usually has some edge preparation. Where plates are to be bent in a fabricating operation, more liberal bend radii must be used, particularly if this bend axis is in the unfavorable (longitudinal) direction.

PART III.9

BELL AND SPIGOT RINGS

Designation: A 306 - 64 (Reapproved 1972)

American National Standard G24.3-1967
American National Standards Institute

AMERICAN SOCIETY FOR TESTING AND MATERIALS

1916 Race St., Philadelphia, Pa., 19103

Standard Specification for CARBON STEEL BARS SUBJECT TO MECHANICAL PROPERTY REQUIREMENTS[1]

This Standard is issued under the fixed designation A 306; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This specification[2] covers carbon steel bars furnished in the as rolled condition, subject to mechanical property requirements and intended for general constructional applications.

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard.

2. General Requirements

2.1 Material furnished under this specification shall conform to the requirements of the current edition of Specification A 29 for General Requirements for Hot-Rolled and Cold-Finished Carbon and Alloy Steel Bars[3] unless otherwise provided herein.

3. Basis of Purchase

3.1 Orders under this specification shall include the following as required to adequately describe the desired material:

3.1.1 Quantity (weight or number of pieces),

3.1.2 Name of material (carbon steel bars),

3.1.3 Cross-sectional shape,

3.1.4 Size,

3.1.5 Length,

3.1.6 Bend test, if required (Section 10.2),

3.1.7 Grade designation or corresponding tensile limits (Section 6.1),

3.1.8 Bessemer steel option, if acceptable (Section 4),

3.1.9 Special straightness, if required,

3.1.10 ASTM designation (A 306), and

3.1.11 End use, exceptions to the specification or special requirements.

4. Process

4.1 The steel shall be made by the open-hearth, basic-oxygen, or electric-furnace process. For Grades 55, 60, 65, and 70, bessemer steel may be supplied subject to agreement between the manufacturer and the purchaser.

5. Ladle Analysis

5.1 The steel shall conform on ladle analysis to the following requirements:

Element	Composition, percent
Phosphorus, max:	
Open-hearth and electric-furnace	0.040
Bessemer	0.11
Sulfur, max:	
Open-hearth and electric-furnace	0.050
Bessemer	0.060
Copper, when copper steel is specified, min	0.20

5.2 When tension tests are waived in accordance with 6.3, chemistry consistent with the mechanical properties desired shall be applied.

6. Tensile Properties

6.1 The material shall conform to the appli-

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.15 on Bar Steels.

Current edition accepted June 15, 1964. Originally issued 1947. Replaces A 306 - 60 T. Grade 65 replaces editions of A 7.

[2] For ASME Boiler and Pressure Vessel Code applications see related Specification SA-306 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Part 3.

cable requirements as to tensile properties prescribed in Table I.

6.2 The yield point shall be determined by the drop of the beam or halt in the gage of the testing machine, or by the use of dividers.

6.3 Shapes less than 1 in.^{2} (6.45 cm^2) in cross section and bars (other than flats) less than ½ in. (13 mm) in thickness or diameter need not be subjected to tension tests by the manufacturer.

6.4 For material over ¾ in. (76 mm) in thickness or diameter, a deduction from the percentage of elongation in 8 in. or 200 mm specified in Table 1 of 0.25 percent shall be made for each increase of ¹⁄₃₂ in. (0.79 mm) in the specified thickness or diameter above ¾ in. (19 mm).

6.5 For material under ⁵⁄₁₆ in. (7.94 mm) in thickness or diameter, a deduction from the percentage of elongation in 8 in. specified in Table 1 of 2.00 percent shall be made for each decrease of ¹⁄₃₂ in. in the specified thickness or diameter below ⁵⁄₁₆ in.

6.6 For Grades 45, 50, 55, 60, and 65, for material over 2 in. (51 mm) in thickness or diameter, a deduction from the percentage of elongation in 2 in. or 50 mm specified in Table 1 of 1.00 percent shall be made for each 1 in. (25 mm) of specified thickness or diameter or fraction thereof over 2 in. in thickness or diameter.

6.7 For Grades 70, 75, and 80, for material over 2 in. in thickness or diameter, a deduction from the percentage of elongation in 2 in. specified in Table 1 of 1.00 percent shall be made for each 1 in. of specified thickness or diameter, or fraction thereof, over 2 in. in diameter or thickness, to a maximum deduction of 3 percent.

7. Bending Properties

7.1 The bend test specimen shall stand being bent cold through 180 deg without cracking on the outside of the bent portion, to an inside diameter which shall have the relation to the thickness or diameter of the specimen given in Table 2.

8. Tension Test Specimens

8.1 Test specimens shall be prepared for testing from the material in its as-rolled condition. However the tension specimen may be aged as described in ASTM Methods and Definitions A 370, for Mechanical Testing of Steel Products.[3]

8.2 Tension test specimens shall be taken longitudinally and may be tested in full thickness or section, or they may be machined to the dimensions shown in Figs. 4 or 5 of Methods A 370. If test specimens are selected conforming to the dimensions of Fig. 5 they shall be machined from a position midway between the center and the surface of the bar.

8.3 Tension test specimens for shapes and flats may be machined to the form and dimensions shown in Fig. 4 of Methods A 370, or with both edges parallel. Test specimens for material over 1½ in. (38 mm) in thickness or diameter may be machined to a thickness or diameter of at least ¾ in. (19 mm) for a length of at least 9 in. (230 mm), or they may conform to the dimensions shown in Fig. 5 of Methods A 370.

9. Bend Test Specimens

9.1 Bend test specimens for material 1½ in. (38 mm) and under in diameter or thickness may be the full thickness of the section. For flat bars over 2 in. (51 mm) in width the width may be reduced by milling to 1½ in.

9.2 Bend test specimens for material over 1½ in. in diameter or thickness may be machined to a thickness or diameter of at least ¾ in. (19 mm), or to 1 by ½ in. (25 by 13 mm) in section. Machined sides of bend test specimens may have the corners rounded to a radius of not over ¹⁄₁₆ in. (1.59 mm) for material 2 in. and under in thickness, and not over ⅛ in. (3.18 mm) for material over 2 in. in thickness.

10. Number of Tests

10.1 Two tension tests shall be made from each heat, unless the finished material from a heat is less than 30 tons when one tension test will be sufficient. If, however, material from one heat differs ⅜ in. (9.53 mm) or more in thickness, one tension test shall be made from both the thickest and the thinnest material (larger than the sizes enumerated in 6.3), regardless of weight represented.

10.2 Shapes less than 1 in.² (6.45 cm²) in cross section and bars, (other than flats) less than ½ in. (13 mm) in thickness or diameter shall be subject to bend tests. All other finished material shall be subject to bend tests only when specified by the purchaser. When subject to bend test, two bend tests shall be made from each heat unless the finished material from a heat is less than 30 tons when one bend test will be sufficient. If, however, material from one heat differs ⅜ in. or more in thickness, one bend test shall be made from the thickest and the thinnest material rolled, regardless of weight represented.

NOTE 2—Bend test should be specified by the purchaser only when the material is to be bent cold during fabrication.

TABLE 1 Tensile Properties

Grade Designation	Tensile Strength, ksi (MPa)	Yield Point, min, ksi (MPa)	Elongation, min, percent: 8-in. or 200 mm Gage Length	Elongation, min, percent: 2-in. or 50 mm Gage Length
45	45 (310) to 55 (380)	22 (150)	27	33
50	50 (345) to 60 (415)	25 (175)	25	30
55	55 (380) to 65 (450)	27 (185)	23	26
60	60 (415) to 72 (495)	30 (205)	21	22
65	65 (450) to 77 (530)	32 (220)	17	20
70	70 (485) to 85 (585)	35 (240)	14	18
75	75 (515) to 90 (620)	37 (255)	14	18
80	80 (550) min	40 (275)	13	17

TABLE 2 Bend Requirements

Grade Designation	Ratio of Bend Diameter to Thickness of Specimen for Thickness in Diameter of Bar, in. (mm): ¾ (19) and under	Over ¾ to 1 (19 to 25), incl	Over 1 to 1½ (25 to 38), incl	Over 1½ to 2 (38 to 51), incl	Over 2 to 3 (51 to 76), incl	Over 3 to 5 (76 to 127), incl	Over 5 (127)
45	flat	flat	½	1	1	2	3
50	flat	½	1	1½	2½	3	3½
55	½	1	1½	2	2½	3	3½
60	½	1	1½	2½	3	3½	4
65	1	1½	2	3	3½	4	5
70	1½	2	2½	3	3½	4	5
75	2	2	3	3½	4	4½	6
80	2	2½	3	3½	4	4½	6

Designation: A 570 - 72

American National Standard G24.38-1974
Approved Sept. 19, 1974
By American National Standards Institute

Standard Specification for
HOT-ROLLED CARBON STEEL SHEET AND STRIP, STRUCTURAL QUALITY[1]

This Standard is issued under the fixed designation A 570; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

This specification has been approved by the Department of Defense for listing in the DoD Index of Specifications and Standards. Proposed revisions should be coordinated with the Federal Government through the Army Materials and Mechanics Research Center, Watertown, Mass. 02172.

1. Scope

1.1 This specification covers hot-rolled carbon steel sheet and strip of structural quality in cut lengths or coils. This material is intended for structural purposes where mechanical test values are required.

1.1.2 The following grades are covered in this specification:

Mechanical Requirements

Grade	Yield Point, min, psi (MPa)	Tensile Strength, min, psi (MPa)
A	25 000 (172)	45 000 (310)
B	30 000 (207)	49 000 (338)
C	33 000 (228)	52 000 (359)
D	40 000 (276)	55 000 (379)
E	42 000 (290)	58 000 (400)

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard.

2. Applicable Documents

2.1 *ASTM Standard:*

A 568, General Requirements for Carbon and High-Strength Low-Alloy Steel Hot-Rolled Strip, Hot-Rolled Sheets and Cold-Rolled Sheets[2]

3. General Requirements for Delivery

3.1 Material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 568, unless otherwise provided herein.

4. Basis of Purchase

4.1 Orders for material under this specification shall include the following information, as required, to describe the required material adequately:

4.1.1 ASTM specification number and date of issue, and grade,

4.1.2 Copper-bearing steel (if required),

4.1.3 Exceptions to the specification or special requirements (if required),

4.1.4 Name of material (hot-rolled sheets or strip),

4.1.5 Condition (Material to this specification is furnished in the hot-rolled condition. Pickled (or blast cleaned) should be specified if required. Material so ordered will be oiled unless ordered dry),

4.1.6 Dimensions, including type of edges,

4.1.7 Coil size requirements, and

4.1.8 Ladle analysis or test report (request, if required).

NOTE 2—A typical ordering description is as follows: ASTM A 570, Grade A, Copper Steel, Hot-Rolled Sheets, 0.075 by 36 cut edge by 96 in.

5. Chemical Requirements

5.1 The cast or heat analysis of the steel shall conform to the requirements prescribed in Table 1.

5.2 *Product Analysis* may be made by the purchaser from finished material representing each heat. The carbon, phosphorus, and sulfur content thus determined shall not exceed that specified in Table 1 by more than 25 percent. When copper steel is specified, the copper

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.19 on Sheet Steel and Steel Sheets.

Current edition approved April 3, 1972. Published June 1972. Originally published as A 570 - 66 T. Last previous edition A 570 - 70.

[2] *Annual Book of ASTM Standards*, Part 3.

content thus determined shall be not less than 0.18 percent.

6. Physical Requirements

6.1 *Tensile Properties*—The material as represented by the test specimens shall conform to the requirements as to tensile properties prescribed in Table 2.

6.2 *Bending Properties*—The bend test specimens shall stand being bent at room temperature in any direction through 180 deg without cracking on the outside of the bent portion to an inside diameter which shall have a relation to the thickness of the specimen as prescribed in Table 3.

7. Test Specimens

7.1 Tension test specimens shall be taken longitudinally.

8. Number of Tests

8.1 Two tension tests and two bend tests shall be made from each heat or from each lot of 50 tons (45.4 mg). When the amount of finished material from a heat or lot is less than 50 tons, only one tension test and one bend test shall be made. When material rolled from one heat differs 0.050 in. (1.27 mm) or more in thickness, one tension test and one bend test shall be made from both the thickest and thinnest material rolled regardless of the weight represented.

8.2 *Retests*—If one test fails, two more tests shall be run from the same lot, in which case both tests shall conform to the requirements prescribed in this specification; otherwise, the lot under test shall stand rejected.

9. Packaging

9.1 *Coil Size*—Small coils result from the cutting of full-size coils for center test purposes. These small coils are acceptable under this specification.

TABLE 1 Chemical Requirements

Element	Composition, percent	
	Grades A, B, C	Grades D and E
Carbon, max	0.25	0.25
Manganese	0.25–0.60	0.60–0.90
Phosphorus, max	0.04	0.04
Sulfur, max	0.04	0.04
Copper, when copper steel is specified, min	0.20	0.20

TABLE 3 Bend Test Requirements

Grade	Ratio of Bend Diameter to Thickness of Specimen
A	0
B	1
C	1½
D	2
E	2½

TABLE 2 Tensile Requirements

	Grade A	Grade B	Grade C	Grade D	Grade E
Tensile strength, min, psi (MPa)	45 000 (310)	49 000 (338)	52 000 (359)	55 000 (379)	58 000 (379)
Yield point, min, psi (MPa)	25 000 (172)	30 000 (207)	33 000 (228)	40 000 (276)	42 000 (290)
Elongation in 2 in. or 50 mm, min, percent, for thicknesses:					
0.2299 to 0.0972 in., incl	27.0	25.0	23.0	21.0	19.0
0.0971 to 0.0636 in., incl	25.0	24.0	22.0	20.0	18.0
0.0635 to 0.0255 in., incl	23.0	21.0	18.0	15.0	13.0
Elongation in 8 in. or 203 mm, min, percent, for thicknesses:					
0.2299 to 0.0972 in., incl	20.0	19.0	18.0	16.0	14.0
0.0971 to 0.0892 in., incl	18.0	17.0	16.0	14.0	12.0

PART III

APPENDIX "B"

Design Specifications

PART III SUBDIVISION

Appendix A

Design Requirements

This appendix is for information only and is not a part of AWWA C302-74.

A1—General

Reinforced concrete pressure pipe covered by this standard shall be designed by the method described herein to resist the internal pressures and external loads designated by the purchaser.

A2—Wall Stress Limits

The circumferential tensile stress in the concrete of the pipe wall, with no allowance for steel reinforcement, shall not exceed $4.5\sqrt{f_c'}$ as determined by Eq (1).

$$f_{ct} = \frac{(P_w + P_t)D}{2_t} \quad (1)$$

f_{ct} = Circumferential tensile stress in the concrete in pounds per square inch

P_w = Working pressure in pounds per square inch

P_t = Transient pressure in pounds per square inch

D = Inside diameter of pipe in inches

t = Wall thickness of pipe in inches

f_c' = 28-day concrete design strength in pounds per square inch

A3—Hydrostatic Design

The cross-sectional area of the circumferential steel reinforcement to resist internal pressure only shall be not less than the maximum determined from Eq (2, 3).

$$A_s = \frac{6P_wD}{16\,500-75P_w} \quad (2)$$

$$A_s = \frac{6(P_w + P_t)D}{16\,500} \quad (3)$$

A_s = Cross-sectional area of circumferential steel reinforcement in square inches per foot of pipe wall

P_w = Working pressure in pounds per square inch

P_t = Transient pressure in pounds per square inch

D = Inside diameter of pipe in inches

A4—Combined-Load Design

The pipe shall be designed to resist the flexural and axial stresses from each of the following conditions:

1. A combination of working pressure, transient pressure, and dead loads (earth, pipe, and water)

2. A combination of working pressure, dead loads, and live loads, and
3. Dead loads and live loads with no internal pressure.

External dead loads and live loads shall be computed in accordance with recognized and accepted theories, such as presented in Ref. 1, 2.

The coefficients for moment and thrust shall also be from recognized and accepted theories, such as presented in Ref. 3, 4. The bedding angle used in design shall be compatible with the installation specified by the purchaser.

The reinforced concrete design shall be in accordance with the applicable provisions of ACI Standard 318 using either the strength method or the alternate design method (working stress method).

For the strength method, the load factor shall be 1.8, the capacity reduction factor ϕ shall be 1.0, the design yield strength f_y shall not exceed 40 000 psi, and an equivalent rectangular concrete stress distribution shall be used.

For the alternate design method, the load and ϕ factors shall each be 1.0, the allowable tensile stress in the reinforcement shall not exceed 22 000 psi, and the calculated compressive stress in the concrete shall not exceed $0.45\ f_c'$.

A5—Reinforcement Cage Configurations

Steel reinforcement shall consist of a single elliptical cage, one or more circular cages, or a combination of an elliptical cage and one or more circular cages.

At least one of the cages shall be circular in pipe designed for a working pressure of more than 20 psi or in pipe larger than 72 in. in diameter. An inner circular cage and an outer circular cage shall be used and may be combined with an elliptical cage in pipe designed for working pressures of more than 40 psi. When the reinforcement consists of a combination of circular and elliptical cages and the working pressure exceeds 20 psi, the total cross-sectional area of the circular cage or cages shall not be less than that determined by Eq (2) with an allowable steel stress of 25 000 psi.

For design of single circular reinforcement, the steel shall be assumed to act at the centerline of the pipe wall. For double circular cages, for an elliptical cage, or for a combination of an elliptical cage and one or more circular cages, the design depth shall be to the centroid of the tensile steel with a design-clear concrete cover of 1/8 in. more than the minimum specified in Sec. 3.5.3.

A6—Longitudinal Beam Strength

If the pipe is to be installed on sleepers or bents or in any other condition that would create longitudinal bending, the required beam strength shall be provided by adjusting either the laying length or the wall thickness, or both, so that the concrete flexural tensile stress does not exceed $4.5\sqrt{f_c'}$. In the determination of the flexural tensile stress, the section modulus of the pipe shall be calculated about the centroidal axis of the transverse section with no allowance for longitudinal steel reinforcement.

Appendix B

References

This appendix is for information only and is not a part of AWWA C302-74.

1. Spangler, M. G. *Soil Engineering.* International Textbook Co., Scranton, Pa. (2nd ed., 1960) p. 396.
2. *Concrete Pipe Design Manual.* American Concrete Pipe Assn., Arlington, Va. (1970).
3. Paris, J. M. Stress Coefficients for Horizontal Pipes. *Engrg. News-Record,* 86:768 (1921).
4. Olander, H. C. Stress Analysis of Concrete Pipe. Eng. Monograph No. 6, US Bureau of Reclamation, Dept. of Interior, Washington, D.C.

DESIGN OF REINFORCED CONCRETE PRESSURE PIPE--TABLE 1

Introduction

The purpose of this article is to briefly present a discussion of the loadings, bedding, design criteria and design procedure used by the United States Bureau of Reclamation in the design of reinforced concrete pressure pipe as specified in Table 1. It is also desirable to prevent the misuse of pipe manufactured in accordance with the designs presented in Table 1 by describing the design assumptions and criteria used in these designs.

Loads

Reinforced concrete pressure pipe is designed for dead load of the pipe itself, earth load, the load due to the weight of water in the pipe, and the load due to the hydrostatic head measured from the inside of the pipe to the design gradient. In using Table 1, special live loads due to highways, railroads, etc., are converted to an equivalent earth load and added to the actual earth load. The assumed distributions of these loads are shown in Figure 1. A study was made of various trench and projection conditions with various types of soil and from this study it was concluded that the earth load could be determined from the following formulae:

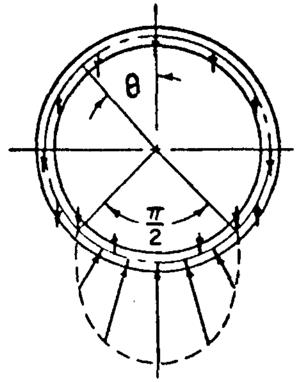
$$A = h \times D_f \times W_e$$

$$W_e = \text{unit weight of earth} + 20\ h/D_f$$

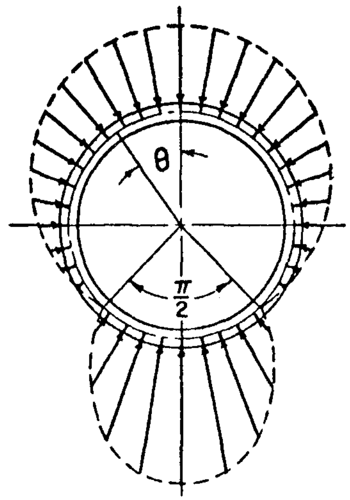
$$\text{Max } W_e = 150$$

Standard designs in Table 1 are based on an assumed weight of earth of 100 pounds per cubic foot.

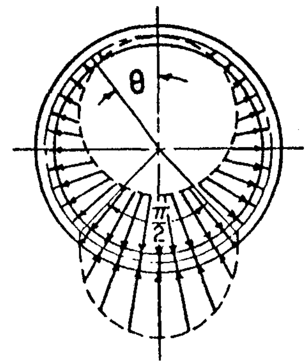
The calculations for Table 1 are based on an assumed bearing over a 90° central angle. Figure 2 shows the bedding required for reinforced concrete pressure pipe. These requirements are to assure that assumptions used in design for pressure distribution are met.



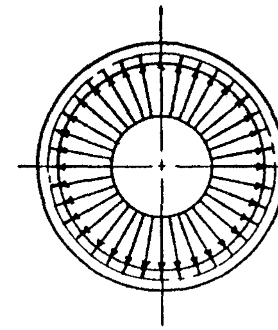
DEAD LOAD



EARTH LOAD



WATER LOAD
(PIPE FULL)

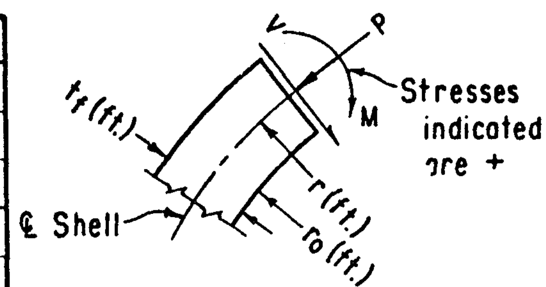


WATER LOAD
(HYDROSTATIC PRESSURE)

COEFFICIENTS AND FORMULAS FOR MOMENTS, THRUSTS AND SHEARS

ANGLE θ			0°	105°	150°	180°	FORMULA	UNIT
MOMENT M	Coeff. X	Dead load	-.070	+.088		-.122	$Xr(300\pi r t_f)$	ft. lbs.
		Earth "	-.067	+.089		-.126	$Xr(100+20\frac{h}{D_f})hD_f$	ft. lbs.
		Water "	-.070	+.088		-.122	$Xr(62.4\pi r_o^2)$	ft. lbs.
THRUST P	Coeff. Y	Dead "	-.061	+.297		+.207	$Y(300\pi r t_f)$	lbs.
		Earth "	+.383	+.539		+.324	$Y(100+20\frac{h}{D_f})hD_f$	lbs.
		Water "	-.220	-.062		-.272	$Y(62.4\pi r_o^2)$	lbs.
SHEAR V	Coeff. Z	Dead "	0	-.017	-.259	0	$Z(300\pi r t_f)$	lbs.
		Earth "	0	-.010	-.273	0	$Z(100+20\frac{h}{D_f})hD_f$	lbs.
		Water "	0	-.017	-.259	0	$Z(62.4\pi r_o^2)$	lbs.

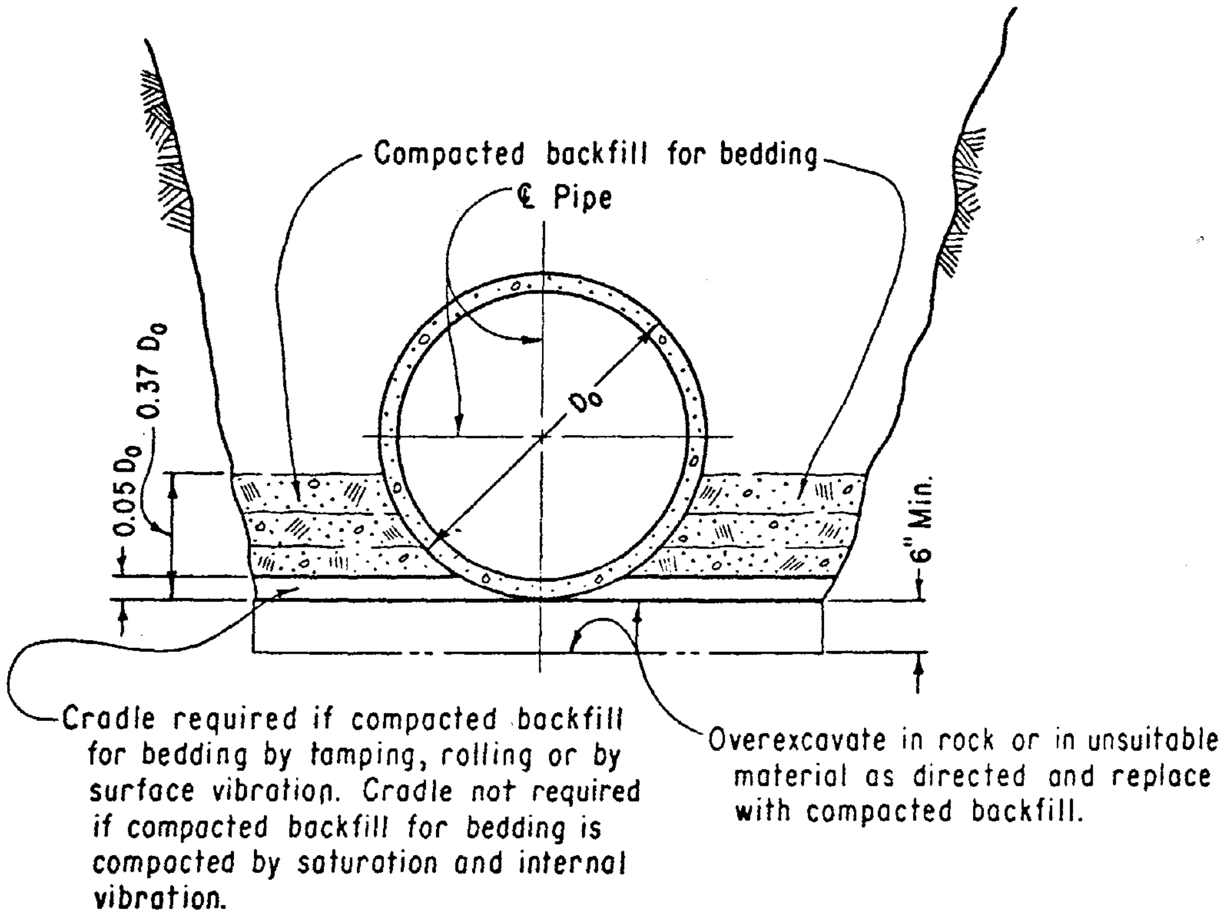
h = height of earth fill above pipe, in feet.
D_f = outside diameter of pipe, in feet.



SIGN CONVENTION

LOAD DISTRIBUTIONS AND COEFFICIENTS FOR MOMENT, THRUST AND SHEAR

FIGURE I



TYPICAL TRENCH
FIGURE 2

Design Criteria

Concrete design is based on a compressive strength of 4,500 psi. Reinforcing steel design is based on a yield point strength of 40,000 psi.

The analysis of stresses in the pipe is based on pressure distributions in accordance with Engineering Monograph No. 6.1/ Values of the coefficients for moment, thrust and shear for the assumed central bedding angle of 90° are given in Figure 1. Experience indicates that shear stresses do not control for the depths of earth covers in Table 1 if the minimum shell thickness in inches is equal to or greater than the inside diameter of the pipe divided by 12. Therefore, shear is not considered in Table 1 design.

For cases where combined internal and external loads are considered, ultimate design theory is used with a load factor of 1.8.

In order to insure water tightness in reinforced concrete pressure pipe a hypothetical case for bursting due to hydrostatic head only is calculated and the following unit stresses in reinforcement are allowed:

Hydrostatic head in feet	f_s due to head only in psi
0 to 50.1	16,000
50.1 to 75.1	14,000
75.1 to 125.1	12,500

For elliptical reinforcement the area of reinforcement is 1.6 times that required for circular reinforcement for hydrostatic head alone.

In accordance with ACI Code 318-63 the reinforcement ratio shall not exceed 0.75 of the ratio which produces balanced conditions at ultimate strength or maximum $p = 0.75 \left[\frac{0.85\ k_1 f'_c}{f_y} \times \frac{87,000}{87,000 + f_y} \right]$. In applying this criterion to pipe design, the case with the pipe full of water, but no internal head is used because this loading gives the maximum compression case.

An investigation of reinforcement cover and bar sizes used by various pipe manufacturers was made. Based on these findings, the following tabulation is given:

Internal diameter of pipe (inches)	Design cover (inches)
45 and less	0.8750
48 through 60	0.9375
63 through 69	1.0000
72 through 108	1.2500

For single layer reinforcement, the steel is assumed to be at the centerline of the cross section. For elliptical reinforcement, at the top and bottom of the pipe, the cover given in the above table is used; whereas, on the side of the pipe where the maximum steel area, based on positive moment is calculated, the steel is assumed to be located at the centerline of the cross section. For pipe with two layers of reinforcement, the cover indicated by the above table is used at all locations.

The minimum longitudinal or radial spacing for circumferential reinforcement is based on aggregate size and is 1-1/2 inches clear for pipe with diameters of 60 inches and less, and 2 inches clear for pipe with diameters greater than 60 inches. The maximum longitudinal spacing is 4 inches center to center of bars. This is an arbitrary spacing made small to help insure watertightness. The maximum reinforcement bar size is a number 11 bar and the minimum size reinforcement is number 8 gage. In determining "d" the largest bar size consistent with the spacing requirements is used since bar size is not specified.

The smallest shell thickness given for a particular pipe diameter is the minimum permitted. As some pipe manufacturers may use thicknesses other than those given in Table 1, steel areas for other shell thicknesses can be arrived at as a straight line proportion between the areas given for the shell thicknesses in the table.

Enough longitudinal reinforcement should be provided to satisfactorily tie the reinforcement cage together, keeping the circumferential reinforcement in place. A minimum of 4 bars and a maximum spacing of 42 inches is specified. It is the responsibility of the pipe manufacturer to provide any additional longitudinal reinforcement which may be necessary to prevent circumferential cracking in the pipe wall and to provide sufficient rigidity to the cage.

Design Procedure

Consider the pipe section with double layer reinforcement shown in Figure 3 and refer to Figure 2 or Reference 1 for calculation of maximum moments and thrusts.

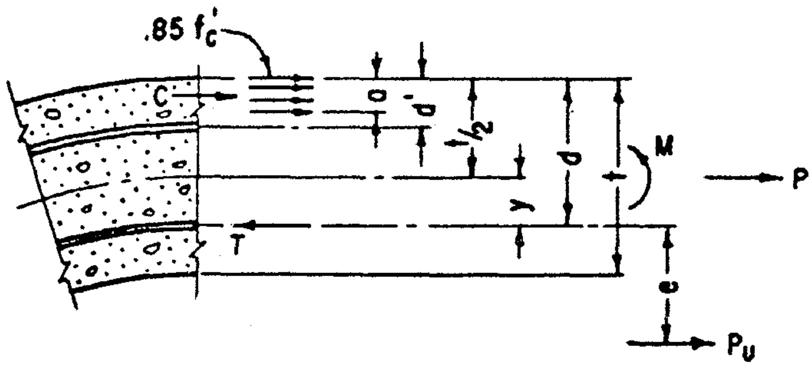


Figure 3

The depth of the compression block, "a" is generally less than "d'." If this is the case, neglecting the ability of the outer layer of steel to take part of the tension will lead to a slightly conservative design. If "a" is greater than "d'" this outer layer of steel will be in the compression zone and the neglect of it will again lead to a slightly conservative design. Neglecting the outer layer of steel, the compressive force

$$C = 0.85\, f_c'\, ba$$

Summing moments about the tensile steel yields

$$e = \frac{M}{P} - y$$

The ultimate moment

$$M_u = P_u e = C\,(d - a/2) = 0.85\, f_c'\, ba\,(d - a/2)$$

Solving for a

$$a = d - \sqrt{d^2 - \frac{2\,M_u}{0.85\, f_c'\, b}}$$

Using a 1.8 load factor

$$M_u = 1.8\,(M - Py) \text{ and}$$

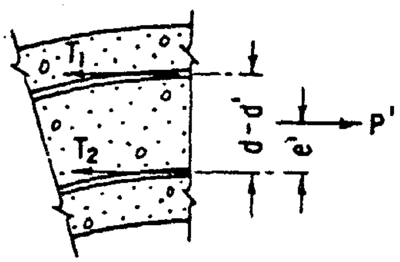
$$P_u = 1.8\,P$$

Finally, the area of reinforcing steel, for the inner layer,

$$A_s = \frac{T}{f_y} = \frac{C + P_u}{f_y} = \frac{C + 1.8\ P}{f_y}$$

Similarly A_s for the outer layer is calculated.

If $M - Py \leq 0$ or $e \leq 0$ there is tension over the entire section and the ultimate design procedure, described above, cannot be used.



$$T_1 = \frac{P'\ e'}{(d - d')}$$

$$T_2 = \frac{P'(d - d' - e')}{(d - d')}$$

Figure 4

Referring to Figure 4, the tensile force in each layer of reinforcing steel is in inverse proportion to the distance of the direct load from the given layer of steel.

For pipe with one layer of reinforcement the design procedure is similar to that outlined above.

It is necessary to check that the area of reinforcement required for the maximum compressive case is less than 75 percent of that required for balanced design as has been discussed.

It is also necessary to check that the sum of the areas of steel for the inner and outer layers as calculated above is adequate for the hypothetical bursting case. If additional reinforcement is required, it is added so that the ratio of the inside steel area to the outside steel area will remain the same.

a = depth of rectangular stress block--inches

b = width of beam--inches

d = distance from extreme compression fiber to centroid of tension reinforcement--inches

d' = distance from extreme compression fiber to centroid of compression reinforcement--inches

e = distance between tension reinforcement and ultimate thrust--inches

e' = distance between tension reinforcement and the equivalent load based on moment and thrust--inches

f'_c = compressive strength of concrete--psi

f_y = yield strength of reinforcement--psi.

h = earth cover--feet

k_1 = a factor defined in Section 1503(g), ACI Code 318-63[2]

p = A_s/bd

r = radius to centerline of pipe wall--feet

r_o = radius to inside of pipe wall--feet

t = thickness of pipe wall--inches

t_f = thickness of pipe wall--feet

y = distance from tension reinforcement to centerline of pipe wall--inches

A = total earth load on pipe--pounds

A_s = area of tension reinforcement--square inches

C = compressive force in concrete--pounds

D_o = outside diameter of pipe--inches

D_f = outside diameter of pipe--feet

M = moment due to dead, earth and water loads--foot-pounds

M_u = ultimate moment--foot-pounds

P = thrust at centerline of pipe due to dead, earth and water loads--pounds

P' = equivalent thrust, eccentrically located, based on P and M--pounds

P_u = ultimate thrust--pounds

T = tensile force in reinforcement--pounds

V = total shear due to dead, earth and water loads--pounds

W_e = effective weight of earth per unit volume--pounds per cubic foot

X = moment coefficient

Y = thrust coefficient

Z = shear coefficient

θ = angle from top of pipe--degrees

References

1. Olander, H.C., "Stress Analysis of Concrete Pipe," Engineering Monograph No. 6, U.S. Bureau of Reclamation, October 1950.

2. ACI Standard Building Code Requirements for Reinforced Concrete (ACI 318-63), American Concrete Institute, 1963.

Appendix A

Design Requirements

This appendix is for information and is not a part of AWWA C300-74.

A1—General

Reinforced concrete cylinder pipe covered by this standard shall be designed by the method described herein to resist the internal pressures and external loads designated by the purchaser.

A2—Hydrostatic Design

To resist internal pressure alone, the cross-sectional area of the circumferential steel reinforcement shall be no less than the maximum determined from equations (1) and (2):

$$A_s = \frac{6P_wD_y}{12{,}500} \qquad (1)$$

$$A_s = \frac{6(P_w + P_t)D_y}{16{,}500} \qquad (2)$$

A_s = Cross-sectional area of circumferential steel reinforcement, including the steel cylinder, square inches per foot of pipe wall

P_w = Working pressure, psi

P_t = Transient pressure, psi

D_y = Inside diameter of steel cylinder, inches

A3—Combined Load Design

The pipe shall be designed to resist the flexural and axial stresses from each of the following load conditions:

1. A combination of working pressure, transient pressure, and dead loads (earth, pipe, and water)
2. A combination of working pressure, dead loads, and live loads
3. Dead loads and live loads with no internal pressure.

External dead loads and live loads shall be computed in accordance with recognized and accepted theories, such as presented in *Soil Engineering* by M. G. Spangler [International Textbook Co., Scranton, Pa. (2nd ed., 1960), pp. 396–418] and in *Concrete Pipe Design Manual* [American Concrete Pipe Assn., Arlington, Va., (1970)].

The coefficients for moment and thrust shall also be from recognized and accepted theories, such as presented in "Stress Coefficients for Large Horizontal Pipes" by J. M. Paris [*Engineering News-Record*, vol. 86, p. 768 (1921)] and in "Stress Analysis of Concrete Pipe" by H. C. Olander [Eng. Monograph No. 6, US Bureau of Reclamation, Dept. of the Interior, Washington, D.C.]. The bedding angle used in design shall be compatible with the installation specified by the purchaser.

The reinforced concrete design shall be according to the applicable provisions of ACI Standard 318, with either the strength method or the alternate design method (working stress method) being used.

For the strength method, the load factor shall be 1.8; the capacity reduction factor, ϕ, shall be 1.0; and an equivalent rectangular concrete stress distribution shall be used. The design yield strength, f_y, shall not exceed 40,000 psi for the sides of the pipe, and the design yield strength shall not exceed the value determined by equations (3a) or (3b) for the crown and invert of the pipe.

f_{yi} = 27,000 psi,
where $A_r < \frac{1}{3}(A_r + A_y)$ (3a)

f_{yi} = 33,000 psi,
where $A_r \geqq \frac{1}{3}(A_r + A_y)$ (3b)

f_{yi} = Design yield strength for the crown and invert of the pipe, psi

A_r = Cross-sectional area of rod reinforcement in the tensile zone of the crown and invert, square inches per foot of pipe wall

A_y = Cross-sectional area of steel cylinder, square inches per foot of pipe wall

For the alternate design method, the load and ϕ factors shall each be 1.0; the calculated compressive stress in the concrete shall not exceed 0.45 f_c' (the specified 28-day compressive strength); and the allowable tensile stress in the reinforcement shall not exceed 22,000 psi at the sides of the pipe and shall not exceed the value determined by equation (4) for the crown and invert of the pipe, with the applicable value of f_{yi} from (3a) or (3b) being used.

$$f_{si} = 0.55 f_{yi} \qquad (4)$$

f_{si} = Allowable tensile stress for the inner layer of steel reinforcement at the crown and invert, psi

When the transient pressure is combined with other loads, the required capacity for the strength method shall be reduced by 25 per cent, or allowable stresses for the alternate method shall be increased by one third. The provisions of this paragraph apply only to load condition 1.

A4—Reinforcement Cage Configurations

Reinforcement shall consist of a steel cylinder and one or more cages. The cages may be circular or elliptical in shape and may be used singly or in combination. The cross-sectional area of the circumferential rod reinforcement per linear foot of pipe shall be no less than 40 per cent of the total area of reinforcement per linear foot of pipe. When the reinforcement consists of a combination containing an elliptical cage, the cross-sectional area of the circular reinforcement, including the steel cylinder, shall be no less than that determined by Eq (1), with an allowable steel stress of 25,000 psi.

The design depth of the pipe wall section shall be taken to the centroid of the tensile steel. The design clear concrete cover for an outer circular cage or for the horizontal axis of an elliptical cage shall be 1½ in. For the steel cylinder, the design clear cover shall be the nominal lining thickness designated by the manufacturer but no less than the minimum lining thickness shown in Table 3 of Sec. 3.1.3.

Appendix A

This appendix is for information only.

Design Procedure

Pretensioned pipe of the type covered by this standard is designed primarily on the basis of safely resisting the specified internal design and transient pressures. Reliance for satisfactory performance of the pipe under certain underground conditions must be placed on the procedures followed in installation of the pipe and placement of the backfill around it, augmented where necessary by special design precautions, so that injurious deflection of the pipe will be prevented (see Foreword).

The average circumferential stress in the steel cylinder and rod reinforcement at design pressure shall not exceed 16,500 psi nor 50 per cent of the specified minimum yield strength of the steel used in the cylinder when computed by the following formula (1):

$$f_s = \frac{P_w 6 D_y}{A_r + A_y} \qquad (1)$$

where

f_s = average circumferential stress in the steel cylinder and rod reinforcement, psi
P_w = design pressure, psi
D_y = inside diameter of cylinder, inches
A_r = cross-sectional area of rod reinforcement, sq in. per ft of pipe wall
A_y = cross-sectional area of steel cylinder, sq in. per ft of pipe wall

In design, determine the cylinder thickness and the area of reinforcement rod per ft of pipe wall on the basis of the foregoing formula (1) and the provisions of Sec. 3.2.2, applying the pipe diameter and the lining thickness required in Sec. 3.1.4. Determine compatible rod size and spacing, and check for compliance with provisions for clearance, mimimum rod reinforcement area and limitation as to per cent of total steel area, as specified in Sec. 3.2.2.

Should it be necessary to provide an allowance for transient pressure greater than 50 per cent of the design pressure, as stipulated in Sec. 3.2.1, the average circumferential stress in the steel cylinder and rod reinforcement under the combined effect of the design pressure and transient pressure shall not exceed 75 per cent of the specified minimum yield strength of the steel used in the cylinder when computed by the following formula (2):

$$f_s = \frac{(P_w + P_t) 6 D_y}{A_r + A_y} \qquad (2)$$

where

f_s = average circumferential stress in the steel cylinder and rod reinforcement, psi
P_w = design pressure, psi
P_t = allowance for transient pressure, psi
D_y = inside diameter of cylinder, inches
A_r = cross-sectional area of rod reinforcement, sq in. per ft of pipe wall
A_y = cross-sectional area of steel cylinder, sq in. per ft of pipe wall

For purposes of adequately resisting external loads, the combined structural properties of the pipe, its bedding, and the constraints provided to prevent its injurious deformation, shall be designed on the basis that the maximum deflection to which the pipe may be subjected after installation underground shall not at any point exceed $D^2/4{,}000$ inches, or such other limitation as may be explicitly authorized by the purchaser in writing, where D is the nominal diameter of the pipe in inches. The deflection of the pipe is identified as the maximum extension of the horizontal diameter or shorten-

PART III. 14

RCCP

ing of the vertical diameter with the pipe in an unwatered condition.

For purposes of such design for resistance to external loads, the wall stiffness of the pipe required in order to limit deflection as specified herein shall be estimated for each reach of pipeline, taking into account the characteristics of the soil in which the pipe trench is to be excavated, the depth of cover over the pipe, the specified methods of excavation and backfill of the trenches, the nature of the backfill material, the specified methods of bedding the pipe, and the superloads resulting from passage of vehicles along or across the surface of the overlying ground, or from any other load to be exerted upon the ground over the pipe. The required wall stiffnesses thus determined shall be compared with the computed wall stiffness of the pipe to be installed in each affected reach of pipeline, such computed stiffness being based on structural properties of pipe proportioned to resist the specified design and transient pressures by application of formulas (1) and (2) of this Appendix A. If such computed stiffness fails to satisfy the requirements for wall stiffness established as hereinbefore specified in any reach of the pipeline, the specified methods of trench excavation, bedding, or backfilling shall be modified so as to improve the control of pipe deflection and the section area of steel cylinder and rod reinforcement per linear foot of pipe wall shall be sufficiently increased within the length of such reach, so that the pipe will have the required wall stiffness throughout all affected reaches.

The term "wall stiffness" as used herein is defined as EI where E is modulus of elasticity and I is transverse moment of inertia per unit length of pipe wall, the factors in the foregoing expression to be dimensionally compatible.

Computed wall stiffness shall be taken as one-fourth the value derived from the composite wall section of the pipe, transformed on the basis that the modulus of elasticity of steel is 7.5 times that of concrete or mortar, and the modulus of elasticity of the concrete or mortar is 4,000,000 psi. The concrete or mortar lining and the exterior mortar coating shall be considered to be structurally bonded to the cylinder and rod reinforcement assembly in a manner providing full shear restraint.

References

Following are references to technical articles useful in connection with the design of pipe for external loading as outlined above.

1. ANDERSON, M. H., CREASMAN, W. C., & SEVITZ, R. C. *A Method of Determining Permissible Earth Cover Loads on Cement-Mortar Lined and Coated Pipe.* Engineering Topic No. 7, American Pipe and Construction Co. (1967).
2. SPANGLER, M. G. *Soil Engineering* 2nd Ed., International Textbook Company Scranton (1960).
3. WATKINS, R. K. & SMITH, A. B Ring Deflection of Buried Pipe, *Journal AWWA*, 59:3 (March, 1967).
4. Installation of Concrete Pipe. AWWA Manual M9, American Water Works Association, New York (1967).
5. Steel Pipe Design and Installation. AWWA Manual M11, American Water Works Association, New York (1964).

PRESTRESSED CONCRETE PRESSURE PIPE

Appendix A

Cubic Parabola Design Method

This appendix is for information only and is not part of AWWA C301-72

The wire area, tension, and spacing under which the wire is wound and the core thickness shall be varied so that the specific combination of design pressure and earth load will fall on or under the design curves in Fig. A (a and b). The resulting design has a transient-load capacity equal to the difference between the design pressure or earth load and the value determined from the extension of the appropriate line for surge pressure or live load until it intersects the transient-load curve. If surge pressure exceeds 40 per cent of design pressure or live load (including impact) exceeds the American Association of State Highway Officials H-20 loading, this greater value should be stated in the supplementary specifications.

The design curve is defined by the following equation:

$$w = \frac{W_o}{\sqrt[3]{P_o}}\left[\sqrt[3]{P_o - p}\right]$$

in which P_o is the internal pressure required to overcome all compression in the core concrete, exclusive of the effect of external load; W_o is nine tenths of the three-edge-bearing load producing incipient cracking in the core, with no internal pressure; p is the maximum design pressure in combination with three-edge-bearing load, w, and is not to exceed 0.8 P_o for lined cylinder pipe [Fig. A (a)]; w is the maximum three-edge-bearing load, equivalent to earth load, in combination with design pressure p.

Three-edge-bearing values of W_o used for design shall be conservatively based on the manufacturer's accumulated test results. Supporting test data shall be provided if required by the engineer.

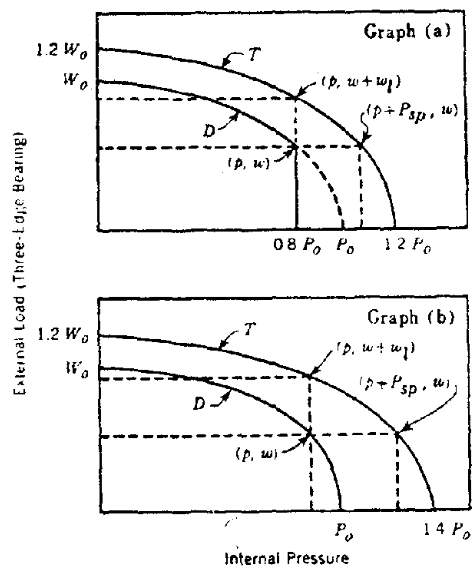


Fig. A. Design and Transient-Capacity Curves for Lined and Embedded Cylinder Pipe Using Cubic Parabola Design Method

Graph (a) is for lined- and Graph (b) for embedded-cylinder pipe. In both graphs, T designates the transient-load curve and D the design curve; w_l is for the three-edge-bearing load equivalent to live load; and P_{sp} is for surge pressure in excess of the normal operating or design pressure.

PART III. 16

PCC & PCEC PIPES

AWWA STANDARD

Appendix B

Stress Analysis Design Method

This appendix is for information only and is not part of AWWA C301-72

The wire area, tension, and spacing under which the wire is wound and the core thickness shall be varied so that the specific combination of design pressure and earth load will fall on or under the design curve illustrated in Fig. B (a and b). The resulting design has a transient-load capacity equal to the difference between the design pressure or earth load and the value determined from the extension of the appropriate line for surge pressure or live load until it intersects the transient-load curve. If surge pressure exceeds 40 per cent of design pressure, or live load (including impact) exceeds the American Association of State Highway Officials H-20 loading, this greater value should be stated in the supplementary specifications.

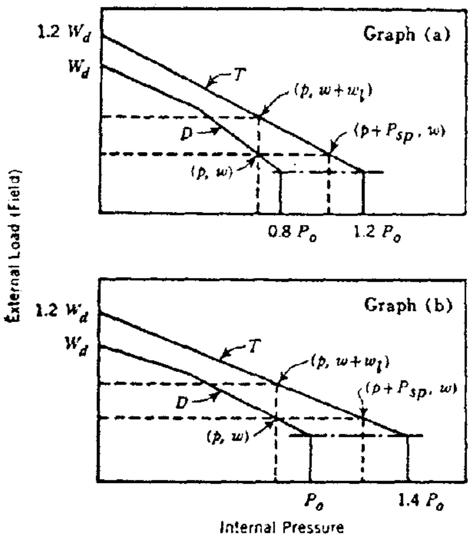


Fig. B. Design and Transient-Capacity Curves for Lined and Embedded Cylinder Pipe Using Stress Analysis Design Method

Graph (a) is for lined- and Graph (b) embedded-cylinder pipe. In both graphs, T designates the transient-load curve and D the design curve; P_o is the internal pressure required to overcome all compression in the core concrete, exclusive of the effect of external load; P_{sp} is the surge pressure in excess of the normal operating or design pressure; W_d is the maximum design field external load with internal pressure equal to zero; and w_l is the live load in excess of the external dead load.

The design curve is defined by the following equation:

$$p = \left[f_{cr} + 7.5\sqrt{f'_c} - \frac{M}{S} \pm \frac{F}{A_t}\right]\frac{A_t}{12R_y}$$

in which p is the maximum design pressure in combination with field external load, w, and is not to exceed 0.8 P_o for lined-cylinder pipe [Fig. B(a)]; f_{cr} is the resultant induced compression; $7.5\sqrt{f'_c}$ is the allowable tensile stress where f'_c is the specified 28-day compressive strength of the concrete; M is the total moment in the pipe section due to pipe weight, water weight, and external load; F is the total thrust in the pipe section due to pipe weight, water weight, and external load; S is the section modulus of the control pipe section based on the total pipe wall at the crown and invert sections and on the core only at the side section; A_t is the transformed cross-sectional area

PCC & PCEC PIPES

the control section based on the total pipe wall at the crown and invert sections and on the core only at the side section; and R_y is the outside radius of steel cylinder.

The coefficients for moment and thrust calculations shall be from recognized and accepted theories, examples of which are to be found in "Coefficients for Large Horizontal Pipes," by J. H. Paris [*Eng. News-Record*, vol. 87, p. 768 (1921)]; and "Stress Analysis of Concrete Pipe," by H. C. Olander [Eng. Monograph No. 6 US Bureau of Reclamation, Dept. of the Interior, Washington, D.C.].

IV. REINFORCED AND PRESTRESSED CONCRETE PIPE DESIGN

1. Planning and Preliminary Design

The flow chart I of Fig. 18 shows the essential steps in the planning and preliminary design of an underground waterpipe line. This chart is self-explanatory and is applicable to the planning and design of an underground waterpipe whatever its material.

2. General Method for the Final Design of Concrete Pressure Pipes

A. Numerous contacts with some of the major manufacturers of concrete pipe and with their manufacturing associations (the American Concrete Pipe Association and the American Prestressed Concrete Pipe Association*) have demonstrated the uniformity of design procedures employed by the industry at the present time. As a consequence of this design uniformity, that is not absolute and still permits a few minor variations in design procedure from firm to firm, the standard products furnished by the various manufacturers are practically identical as they are the result of the same general design method. The flow chart II of Fig. 19 gives a resume of this method and includes most of the loading conditions and design considerations used by the various manufacturers.

The design methods used by the industry at the present time follow the general recommendations and specifications outlined by:

a) the American Water Works Association (Ref. 10-13)

b) the Bureau of Reclamation (Ref. 14-18)

c) the American Concrete Pipe Association (Ref. 20), and

d) the American Prestressed Concrete Pipe Association.

*Located at: 8320 Old Courthouse Road, Vienna, Virginia 22180

FLOW CHART I

PLANNING & PRELIMINARY DESIGN OF UNDERGROUND WATERPIPE LINES

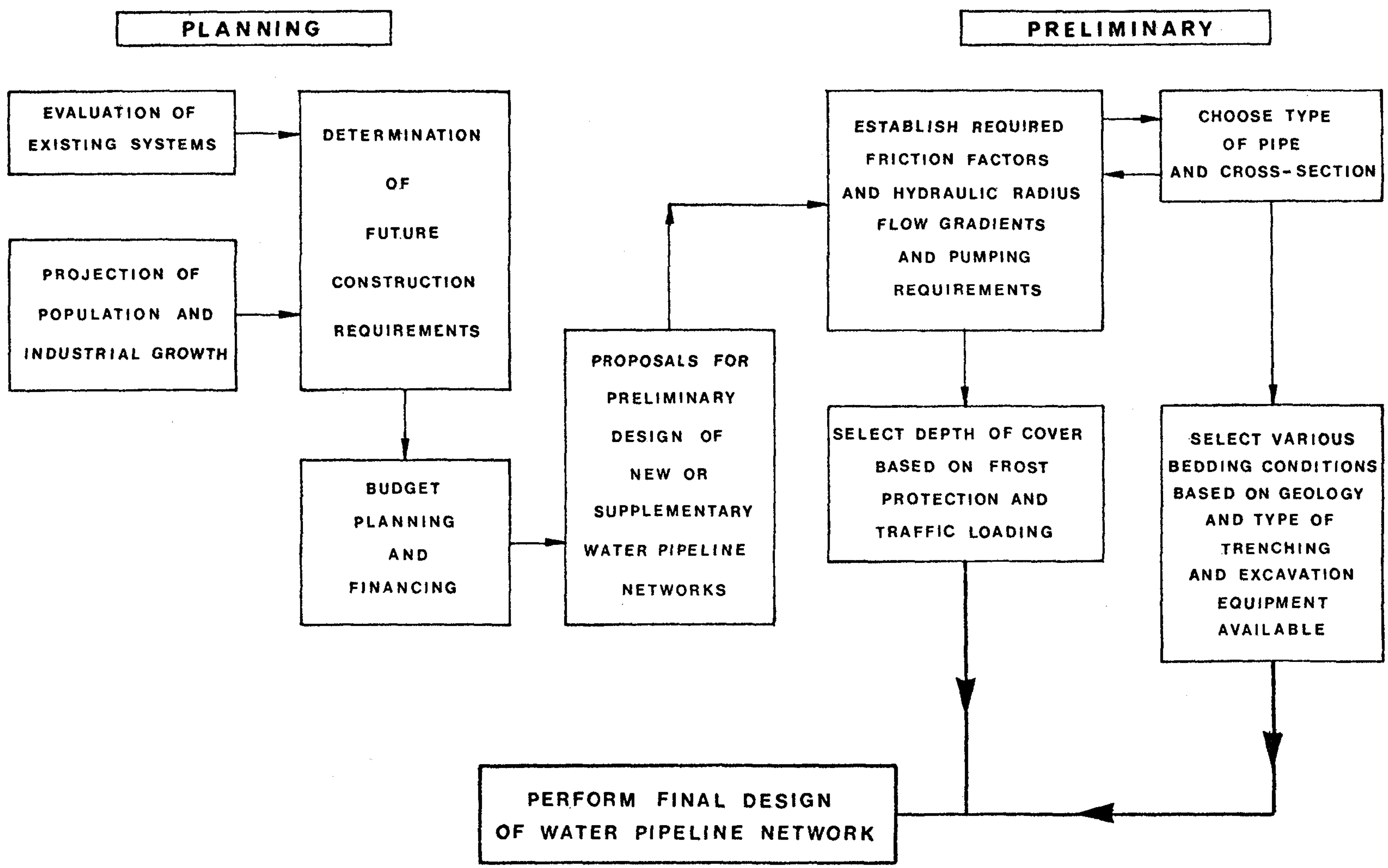


FIG. 18

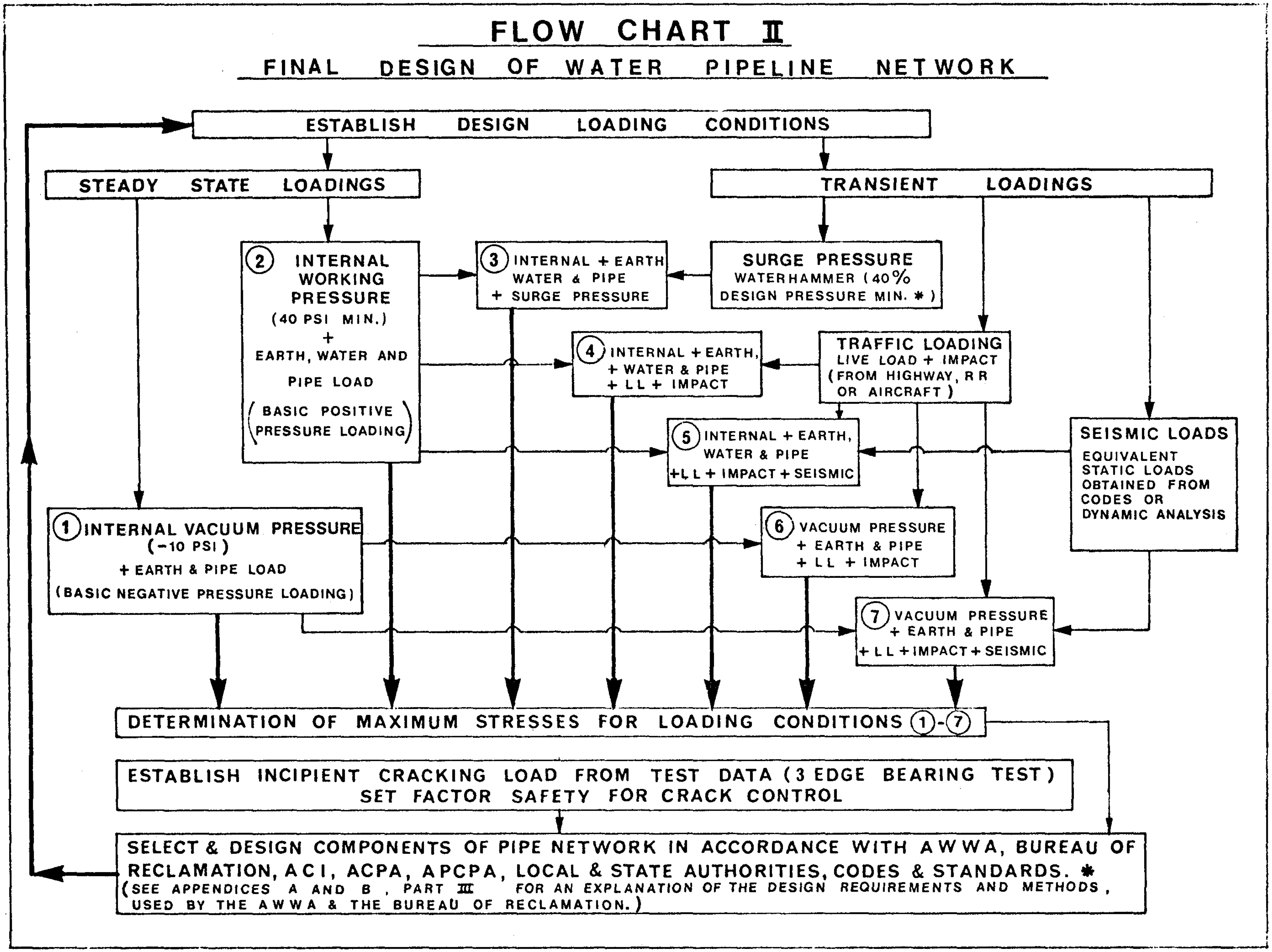

FLOW CHART II
FINAL DESIGN OF WATER PIPELINE NETWORK
ESTABLISH DESIGN LOADING CONDITIONS
STEADY STATE LOADINGS
TRANSIENT LOADINGS
2 INTERNAL WORKING PRESSURE (40 PSI MIN.) + EARTH, WATER AND PIPE LOAD (BASIC POSITIVE PRESSURE LOADING)
3 INTERNAL + EARTH WATER & PIPE + SURGE PRESSURE
SURGE PRESSURE WATERHAMMER (40% DESIGN PRESSURE MIN. *)
4 INTERNAL + EARTH, + WATER & PIPE + LL + IMPACT
TRAFFIC LOADING LIVE LOAD + IMPACT (FROM HIGHWAY, RR OR AIRCRAFT)
5 INTERNAL + EARTH, WATER & PIPE +LL + IMPACT + SEISMIC
SEISMIC LOADS
EQUIVALENT STATIC LOADS OBTAINED FROM CODES OR DYNAMIC ANALYSIS
1 INTERNAL VACUUM PRESSURE (-10 PSI) + EARTH & PIPE LOAD (BASIC NEGATIVE PRESSURE LOADING)
6 VACUUM PRESSURE + EARTH & PIPE + LL + IMPACT
7 VACUUM PRESSURE + EARTH & PIPE + LL + IMPACT + SEISMIC
DETERMINATION OF MAXIMUM STRESSES FOR LOADING CONDITIONS 1-7
ESTABLISH INCIPIENT CRACKING LOAD FROM TEST DATA (3 EDGE BEARING TEST) SET FACTOR SAFETY FOR CRACK CONTROL
SELECT & DESIGN COMPONENTS OF PIPE NETWORK IN ACCORDANCE WITH AWWA, BUREAU OF RECLAMATION, ACI, ACPA, APCPA, LOCAL & STATE AUTHORITIES, CODES & STANDARDS. *
(SEE APPENDICES A AND B, PART III FOR AN EXPLANATION OF THE DESIGN REQUIREMENTS AND METHODS, USED BY THE AWWA & THE BUREAU OF RECLAMATION.)

FIG. 19

Design information on and guidelines for concrete, steel reinforcement, steel cylinder plate, and prestressing wires are also provided by:

a) the American Concrete Institute (Ref. 1 and 2),

b) the Prestressed Concrete Institute (Ref. 3 and 4), and

c) the Portland Cement Association (Ref. 5).

Design information relating to earth and traffic loading, pipe hydraulics and bedding conditions is also given by:

a) the Bureau of Public Road (Ref. 6),

b) the Transportation and Highway Research Boards (Ref. 7),

c) the U.S. Army Corps of Engineers (Ref. 8 and 9).

d) the American National Standard Institute (Ref. 21), and

e) the American Society of Civil Engineers (Ref. 35).

B. In general, concrete water pressure pipes are designed as rigid pipes with no significant short term differential displacements along their length, either vertically or horizontally. In other words, the essential part of the design involves only ring stresses (see p.6 of IR-3 for discussion of this condition in cast-iron pipes.) As the pipe industry is primarily concerned with long term serviceability and crack control and as engineering practice does not allow, at the present time, for sophisticated stress-analysis by elasto-plastic theory using finite-element methods (see Part VII, p.233), the current design methods rely mostly on the empirical results of so-called 3-edge bearing tests, performed in the laboratory to establish practical limits on the strains in the steel and the concrete due to the superimposed vertical loads of earth cover and traffic. In a 3-edge bearing test the pipe is supported along two longitudinal line supports (symmetrically located about the vertical symmetry axis of the pipe) and loaded by a longitudinal line load at its crown. (The 3-edge bearing test producers are described in ASTM C497, reproduced in Appendix A.) Various parabolic interaction curves for the allowable and the ultimate 3-edge bearing-test load (in lbs/lineal foot) versus the internal operating pressure (in psi) have been established empirically for the different types of pipe (see ANSI A21.1 or AWWA C101 and AWWA C-300, C-301, C-302 and C-303) and are utilized to safeguard against the occurrance of unacceptable tensile stresses in the ring and, hence, significant cracking of the concrete core.

In order to convert the 3-edge bearing test load to an equivalent field load, load <u>factors</u> (L_f) have been developed that represent the ratios of the pipe supporting strength in the field to the strength demonstrated in the 3-edge bearing tests.

C. The field supporting strength of a rigid pipe depends chiefly on two characteristics of the installation: a) the width of bedding of the pipe and the type of contact between pipe and bedding, that affect the distribution of the vertical soil reaction; and b) the intensity of the lateral soil pressure on the sides of the pipe and the area of the pipe against which this lateral pressure is exerted, that affect the ovalization of the pipe.

With reference to the first of these characteristics, several classes of bedding have been established and minimum load factors have been computed for each class on the basis of the reaction distribution for that class (see II.3 for bedding classification and load factors.)

The second characteristic, involving the distribution of lateral soil pressure, is a function of the horizontal deformation of the pipe at the spring line as it ovalizes under the superimposed loads. When these deformations are small (less than 01. percent of the pipe diameter), the pipe is arbitrarily considered rigid and no redistribution of the passive earth pressure is assumed to occur around the pipe. This conservative assumption is usually made in designing RC, RCC, PCC and PCEC pipes.

When the horizontal deformations are between 0.1 percent and 3.0 percent of the pipe diameter, the pipe is considered to be semi-rigid and a redistribution of the passive lateral pressure is assumed to take place in determining the ring bending forces due to the superimposed vertical loads. This is done by the use of Spangler's equation (see Ref. 36), which was derived for flexible pipes and is based on the pressure distribution of Fig. 23 where:

W = superimposed load per unit length

r = pipe mean radius

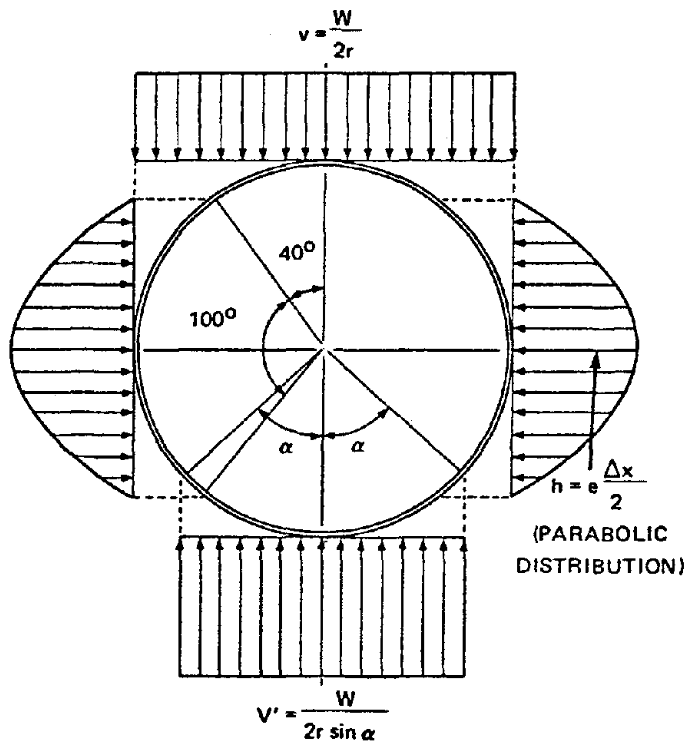
α = bedding angle

h = maximum horizontal pressure

$\Delta x = 4Cr^2$ = maximum horizontal deflection (C = .00025)

e = modulus of passive resistance of side-fill material

Spangler's formula evaluates Δx as a function of the superimposed load, the pipe bedding, the lateral settlement of the side-fill, the pipe mean radius and its flexural rigidity (EI), and the soil modulus.



PRESSURE DISTRIBUTION ASSUMED BY SPANGLER

FIG. 23

Since the modulus of elasticity of the concrete E and the moment of inertia I of the ring cross-section appear in Spangler's formula for Dx and since both E and I vary around the circumference of the pipe due to cracking, composite sections for the pipe are arrived at by assuming that cracking is limited to 100° arcs at the springline and to 60° arcs at the crown and the invert which results approximately in the same flexibility at both sections. As the stress-strain curve for the concrete, particularly in the length tensile region is non-linear, a reduced effective concrete modulus $E = 4x10^6$ is used. Deflections computed for a number of test pipe section using 25 percent of the composite moment of inertia are reasonably close to experimental results.

RCCP pipes are designed as semirigid pipes according to AWWA Standard C303 (see Ref. 36 for the details of such design).

When the horizontal displacement of the pipe at the springline exceeds 3.0 percent of the pipe diameter, the pipe is considered flexible and Spangler's pressure distribution and equation are used to establish the redistributed ring pressure due to superimposed loads.

At the present time, no concrete pipes are usually designed as flexible. Once the final pressure distribution intensity due to superimposed loads is established, the allowable design stresses due to the combined superimposed loads, the operating pressure and surge, the negative vacuum pressure from shut-down and the static equivalent seismic shock are checked by means of linear interaction curves of the external superimposed loads (in lbs. for lineal foot) vs the internal pipe pressure (in psi) (see Part III Appendix B for AWWA standards C300, C301 and C302 giving such curves and the corresponding stress analysis design methods, and Sections IV-5 and IV-6 for examples of design of PCC and PCEC pipes).

A number of additional stresses are checked in the design of pipes, which will not be considered in this report. Among them are:

a) Stresses due to handling, transportation and erection.

b) Stresses due to temperature variation after erection.

c) Stresses due to changes in direction of the line.

d) Local longitudinal and ring stresses due to prestressing discontinuities, gasket reactions and temperature variations after installation.

e) Temporary longitudinal stresses at the joints due to prestressing, which are relaxed by concrete creep, wire relaxation and plastic redistribution.

The general design methods of this section are applied to PCC and PCEC pipes in Sections IV.5 , IV.6 and Section VI, in order to determine the actual maximu operating stresses in the pipes, the pipe ultimate strength and hence, the static reserve of strength of the pipe.

3. General Design Parameters

The main design parameters common to the design of all concrete pipes are:

a) p_w - the positive working or design pressures which are the maximum and minimum internal pressures caused by the hydraulic gradient and the flow of water. (These pressures are assumed to create steady state stress conditions in the pipe.)

b) p_s - the surge pressure caused by water hammer conditions in the pipe. The minimum p_s is 1.4x the design pressure as required by AWWA standards.

c) W_e - Longitudinal superimposed earth load per lineal foot along the pipe. (A minimum of 6' of cover must be assumed with ordinary bedding (class C) according to AWWA standards.) This parameter is a function of the unit weight of the soil, the construction classification for the pipe installation (see II-1), and the bedding (or support) conditions (see II.3).

d) W_{LL+I}- Longitudinal traffic live load per lineal foot of pipe including impact. Load intensities are usually based on a spatial stress distribution in a semi-infinite elastic medium according to Boussinesg's or other theories.

e) W_s - Seismic loads, usually represented by equivalent static loads per unit of vertical projected area of pipe applied to opposite sides of the pipe. At this time these loads are crudely estimated from code guidelines, or from simplified dynamic analyses which attempt to simulate the soil environment interaction by the use of a limited number of degrees of freedom. Even these static seismic loads are seldom taken into account by the manufacturers.

f) p_{neg} - The minimum negative internal pressure (partial vacuum) caused by a shut-down in the pumping and hydraulic systems.

g) W_o - The three-edge bearing load - the test bearing load per lineal foot of pipe, at zero internal pressure, which produces incipient cracking in the concrete cylinder or core (see ASTM C497 for description of standard test methods).

h) L_f - The load factor, used to convert the three-edge bearing (test) load to an equivalent superimposed vertical load (lbs/linear foot) which takes into account the actual construction conditions of the pipe installation. (see Part II.3.)

4. RC, RCCP and RCC Pipe Design

The design of these pipes is based on the theory of reinforced concrete composite sections and does not present aspects peculiar to pipes.
Part III, Appendix B contains the design procedures used by the Bureau of Reclamation for the checking of RC pipes, the AWWA Standard C302 for the same pipes, the AWWA Standard C303 for the RCCP pipes, and the AWWA Standard C300 for the RCC pipes, and illustrates the approach common to such designs.

5. The Design of PCC and PCEC Pipes

This and the following section illustrate the design procedures and two examples of a PCC and a PCEC pipe design as performed by major manufacturers.

WA was provided by major manufacturers with typical design examples, computer outputs of such designs, test reports, experimental graphs, technical articles, and library references as background material for the examples in Section IV.6.

As there are slight variations in the detailed design procedures of the different major pipe manufacturers, WA has attempted to incorporate their governing design criteria and consideration into two all encompassing design examples.

These are believed to present a comprehensive unified design approach typical of industry's approach today.

In working up these typical designs, three main design considerations have been dealt with in detail:

A. The Pipe Loading Input -

Based on engineering theories and judgements which represent the best approximation to the actual loading the pipe will receive from the internal pressure and the external loads.

B. The Crack Control - Serviceability Criteria -

The industry has defined the point of incipient cracking to be the appearance of .001" wide x 1'-0" long microscopic cracks (not visible to the naked eye, see ref. 37). Nine tenths of the three-edge-bearing load causing this type of cracks is taken as the design three-edge bearing load at zero internal pressure, which is the starting point of the cubic parabola interaction curve, for working-design as defined by the AWWA Standard C301, for a given pipe and given construction conditions (soil environment and class of bedding).

C. The Working Stress Criteria -

Based on an allowable tension in the concrete core of $7.5\sqrt{f_c'}$ (where f_c' is the ultimate 28 day compressive strength of the concrete), the AWWA Standard C301 gives a method for determining straight line interaction curves for allowable loads or stresses in the precompressed core versus the internal pressures at the crown, the springline and the invert locations for a given pipe and construction conditions are determined from these curves.

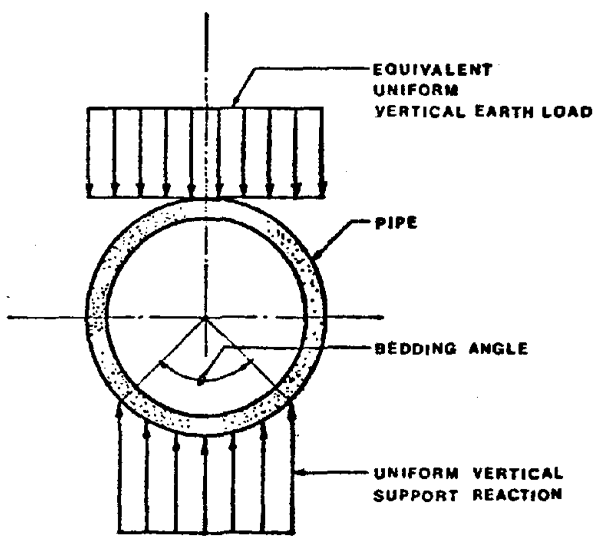
Coefficients are used by industry to determine the maximum moments and thrusts in the pipe at the crown, the springline and the invert for the working stress criteria.

Two different methods have been used to obtain these coefficients.

Paris, in 1921, (see Ref. 45) using elastic arch theory, broke down the solutions into superposition of stresses due to linear distributions of external vertical loads or reactions (see Fig. 23A). Orlando, in 1950 (see Ref. 18) assumed instead bulb-type pressure distributions for the external loads and reactions, (see Fig. 23B).

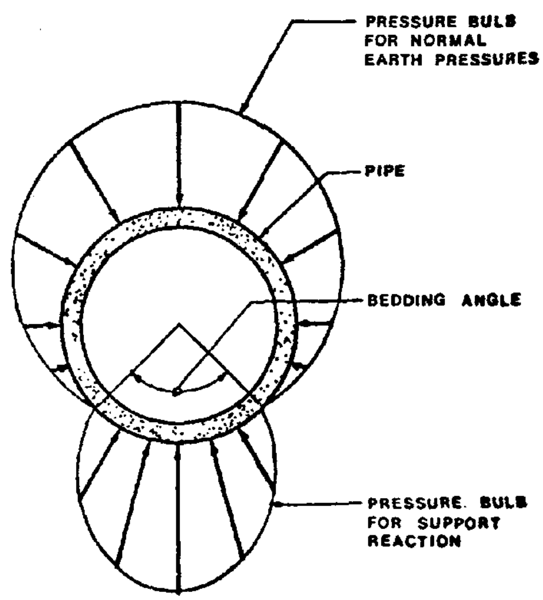
Both sets of coefficients are used by industry today. With Paris' coefficients, only the vertical components of the external loads are considered and no horizontal soil pressure is taken into account. This conservative approach results in larger coefficients for the moments and smaller coefficients for the thrusts. With Orlando's coefficients some horizontal reactions from the normal soil pressures are taken into account, on the basis of Marston's work at the Iowa Engineering Experiment Station (see Ref. 46-48) leading to a less conservative approach with smaller moments and large thrusts.

When static horizontal seismic pressures are added to Paris' vertical loads and reactions, a distribution of external loads similar to that of Orlando is obtained.



PIPE MODEL FOR
EARTH LOAD USING
PARIS FORCE
COEFFICIENTS

FIG. 23 A



PIPE MODEL FOR
EARTH LOAD USING
ORLANDO'S FORCE
COEFFICIENTS

FIG. 23 B

DESIGN EXAMPLES FOR A PCC AND PCEC PIPE

In Example A for the PCC pipe and Example B for the PCEC pipe following, WA has used the standard nomenclature used by the industry (see pages 110 and 111). On pages 112-113, Tables IX and X, giving typical pipe material properties, have been reproduced from manufacturers standard data sheets. Figure 20, on page 114 for the loss paramater β, and the general formulas used in the design examples have also been reproduced from manufacturers graphs. Figure 21, on page 115, is a non-dimensional plot of the AWWA Standard C301 design interaction formula for use in the design examples. Figure 22, on page 116, contains a family of curves compiled by WA from manufacturers data and technical reports (see ref. 37, 39 and 41), which give in terms of the concrete core stress conservative lower bounds for three-edge-bearing loads at incipient cracks of .001 in. Fig. 22 is valid for standard cores for pipe diameters from 16-60".

NOMENCLATURE FOR PCC AND PCEC PIPES

Internal Pressure Classifications (psi):

P_w = Working or design pressure

P_t = Test pressure

P_s = Pressure due to water hammer or surge

P_o = Pressure which counteracts the force of the circumferential prestressing and results in zero concrete stress in the core

P_L = Pressure at which the prestressing wire is stressed to 0.75 f_{su}

P_b = Bursting pressure for pipe based on failure of the cylinder and the circumferential prestressing

Wire Stresses (psi):

f_{sg} = Gross wrapping stress

f_{si} = Initial wire stress

f_{su} = Ultimate strength of wire

f_{sr} = Resultant wire stress

Δf_{s1} = Wire stress change due to concrete inelastic strain

Δf_{s2} = Wire stress change due to P_o

Δf_{s3} = Wire stress change due to P_1

L_1 = Loss due to elastic shortening of core

L_2 = Loss due to wire relaxation

L_3 = Loss due to wire embedment (embedded cylinder pipe only)

Cylinder Stresses (psi):

f_{yi} = Initial cylinder stress

f_{yr} = Resultant cylinder stress

f_{yb} = Stress in cylinder at bursting pressure

Δf_{y1} = Cylinder stress change due to concrete inelastic strain

Δf_{y2} = Cylinder stress change due to P_o

Δf_{y3} = Cylinder stress change due to P_1

Concrete Stresses (psi):

f_{ci} = Initial concrete core stress

f_{cr} = Resultant concrete core stress after relaxation and creep losses

Δf_{c1} = Concrete core stress change due to concrete inelastic strain

f_c = Concrete compressive strength at time of wrapping

Strains:

e_c = Concrete core creep strain

e_{c1} = Concrete core elastic strain due to core creep strain

e_{s1} = Wire elastic strain due to core creep strain

e_{y1} = Cylinder elastic strain due to core creep strain

Additional Symbols:

A_c = Net concrete core area, sq. in. per lin. ft.

A_s = Area of prestressing wire, sq. in. per lin. ft.

A_y = Cylinder area, sq. in. per lin. ft.

C_r = Concrete core creep factor, ratio of inelastic strain to elastic strain

D_y = Outside diameter of cylinder, inches

E_{ci} = Initial concrete core modulus of elasticity, psi

E_{cr} = Resultant concrete core modulus of elasticity, psi

E_s = Steel modulus of elasticity (wire and cylinder equal), psi

n_i = Initial modular ratio, $n_i = E_s/E_{ci}$

n_r = Resultant modular ratio, $n_r = E_s/E_{cr}$

R_1 = Wire relaxation loss factor, $L_2 = R_1 f_{sg}$

R_2 = Wire embedment loss factor, $L_3 = R_2 f_{sg}$

p = Wire steel ratio, A_s/A_c

p' = Cylinder steel ratio, A_y/A_c

PIPE RING DATA FOR CONCRETE CORE

WIRE RELAXATION AND CYLINDER STRESS

PRESTRESSED CONCRETE CYLINDER PIPE – PCC
PRESTRESSED CONCRETE EMBEDDED CYLINDER PIPE–PCEC

	Description	Centrifugated Concrete For PCC	Cast Concrete For PCEC
E_{ci}	Initial Conc. Core - Mod. of Elast.	4.7×10^6 psi	4.0×10^6 psi
E_{cr}	Resultant Conc. Core - Mod. of Elast.	5.6×10^6 psi	4.7×10^6 psi
E_s	Wire & Cylinder-Steel Mod. or Elast.	28×10^6 psi	28×10^6 psi
n_i	Es/Eci - Initial Mod. Ratio	6.0	7.0
n_r	Es/Ecr - Resultant Mod Ratio	5.0	6.0
C_r	Conc. Core Creep Factor - $\frac{\text{inelast. strain}}{\text{elastic strain}}$	1.50	2.00
R_1	Wire Relaxation Loss Factor	0.05	0.05
R_2	Wire Embedment Loss Factor	0	0.05

TABLE IX

Concrete Strength and Maximum Allowable Stress for Wrapping

Concrete strength at time of wrapping, f_c

$f_c = \frac{f_{ci}}{.55}$ but not less than 3500 psi for PCC, 3200 psi for PCEC

Maximum initial concrete stress: PCC				
Diameter	16" - 20"	24" - 30"	36"	42" & 48"
Max. f_{ci} (psi)	3000	2850	2600	2400

Maximum initial concrete stress: PCEC		
Diameter	24" - 36"	42" and larger
Max. f_{ci} (psi)	2500	2250

Cylinder stress for Pipe Bursting:

PCC f_{yb} = 41,000 psi

PCEC f_{yb} = 45,000 psi

PIPE RING DATA FOR CIRCUMFERENTIAL WRAPPING WIRE AND PROTECTIVE COATING - PCC AND PCEC PIPES

			TYPE II WIRE		TYPE III WIRE		TYPE IV WIRE	
WIRE SIZE	CROSS SECTIONAL AREA A_s $in.^2$	NORMAL LIMITS OF SPACING OF CIRCUM. WIRES in.	WRAPPING STRESS f_{sg} psi	MINIMUM ULTIMATE STRENGTH f_{su} psi	WRAPPING STRESS f_{sg} psi	MINIMUM ULTIMATE STRENGTH f_{su} psi	WRAPPING STRESS f_{sg} psi	MINIMUM ULTIMATE STRENGTH f_{su} psi
#8	.0206	3/8" - 1-1/2"	173,250	231,000	196,500	262,000	219,750	293,000
#6	.0290	3/8" - 1-1/2"	166,500	222,000	189,000	252,000	211,500	282,000
1/4"	.0491	7/16" - 5/8"	158,250	211,000	180,000	240,000	201,750	269,000
5/16"	.0767	7/16" - 5/8"	150,750	201,000	165,750	221,000	---	---

TABLE X

WIRE LOSSES

Due to Wire Relaxation: $L_2 = R_1 f_{sg}$

where $R_1 = 0.05$ for PCC and PCEC Pipes

Due to Wire Embedment: $L_3 = R_2 f_{sg}$

where $R_2 = 0.$ for PCC Pipe

and $R_2 = 0.05$ for PCEC Pipe

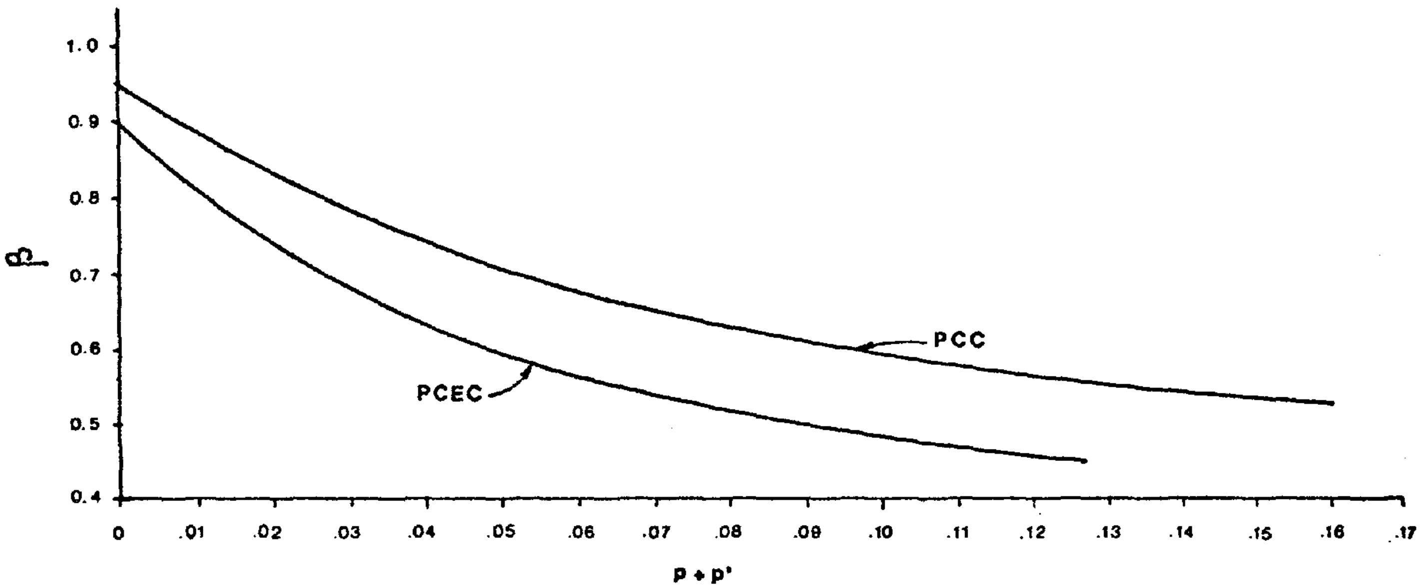
COATING DATA

Nominal brush mortar thickness:

#8 wire	- 13/16"
#6 wire	- 13/16"
1/4" wire	- 7/8"
5/16" wire	- 15/16"

Nominal poured concrete thickness:

54" pipe to 114" pipe	- 1-1/2"
120" pipe to 144" pipe	- 2"



CURVES OF LOSS PARAMETER β FOR PCC AND PCEC PIPES

Where: $\beta = \dfrac{(1-R_1-R_2)\ [1+n_r\ (p+p')]^2}{[1+n_i\ (p+p')]\ [1+n_r\ (p+p')\ (1+C_r)]}$ (Ref. 44, p.9-10)

GENERAL FORMULAS REQUIRED IN DESIGN:

$$P_o = \frac{A_c\ p\ f_{sg}\beta}{6D_y}; = \frac{f_{cr}}{6D_y}\ [A_{ct} N_r (A_s + A_y)] \qquad P_L = \frac{f_{sg}}{6D_y}\ [A_s + A_y\ (R_1 + R_2)] \geq 1.70\ P_w$$

$$P_b = \frac{A_s f_{su} + A_y f_{yb}}{6D_y};\ f_{cr} = \frac{p f_{sg}\ \beta}{1+n_r\ (p+p')} = f_{ci}\left[\frac{A_c + n_r(A_s + A_y)}{A_c + n_r (A_s + A_y)(1+C_r)}\right]$$

(For Formula Derivations, see Ref. 19, p.8-10, Ref. 39, p.1055-1057, Ref. 44, p. 5-12)

Fig. 20

PART IV

PLOT OF CUBIC PARABOLA INTERACTION

FORMULA OF AWWA C 301 $W = W_O \sqrt[3]{\frac{P_O - P}{P_O}}$

FOR COMBINED STRESSES

FROM 3 EDGE BEARING AND INTERNAL PRESSURE

FOR PRESTRESSED CONCRETE CYLINDER PIPE – PCC

AND PRESTRESSED CONCRETE EMBEDDED CYLINDER – PCEC

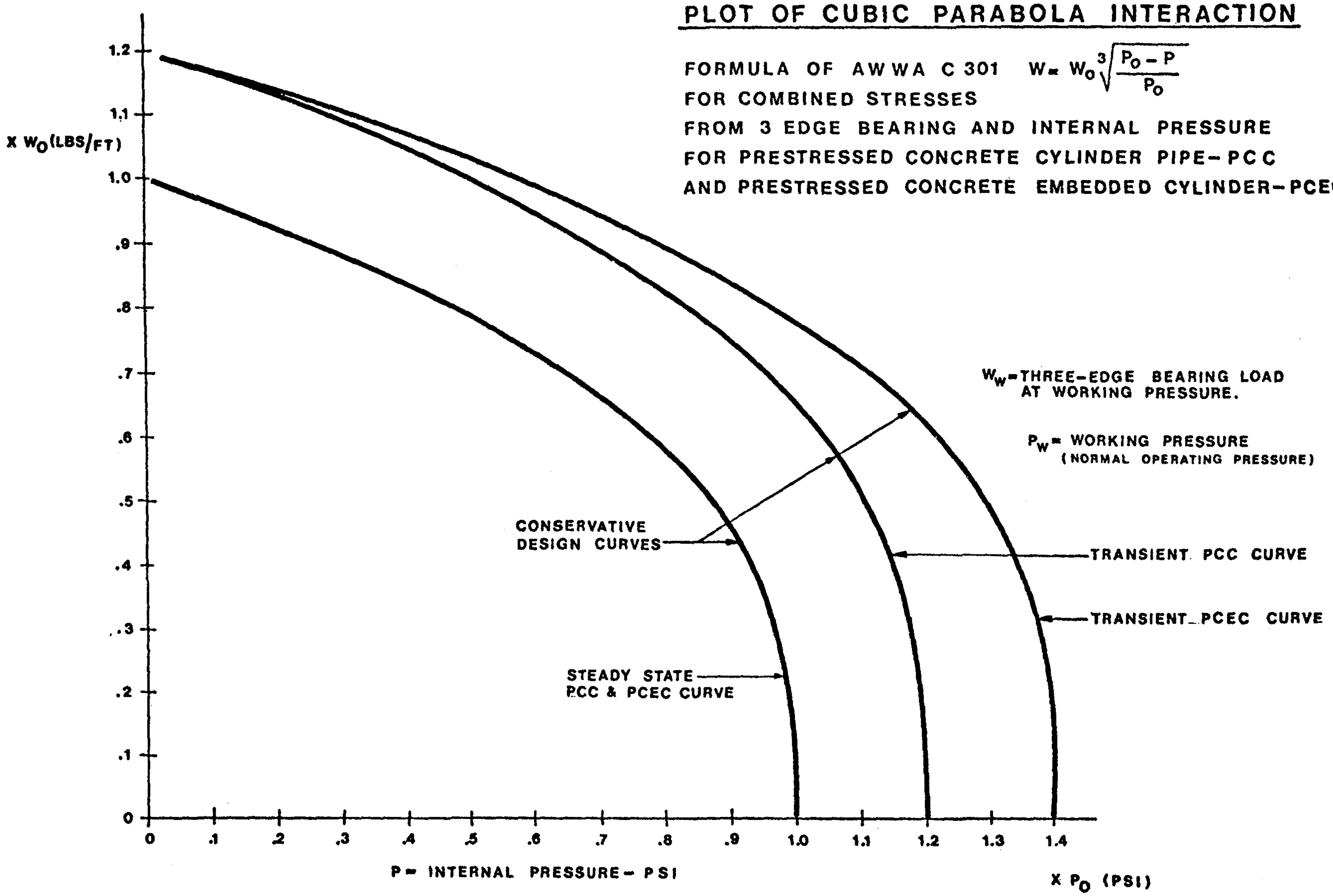


FIG. 21

PART IV

THREE-EDGE BEARING LOAD vs. RESULTANT CONC. CORE STRESS

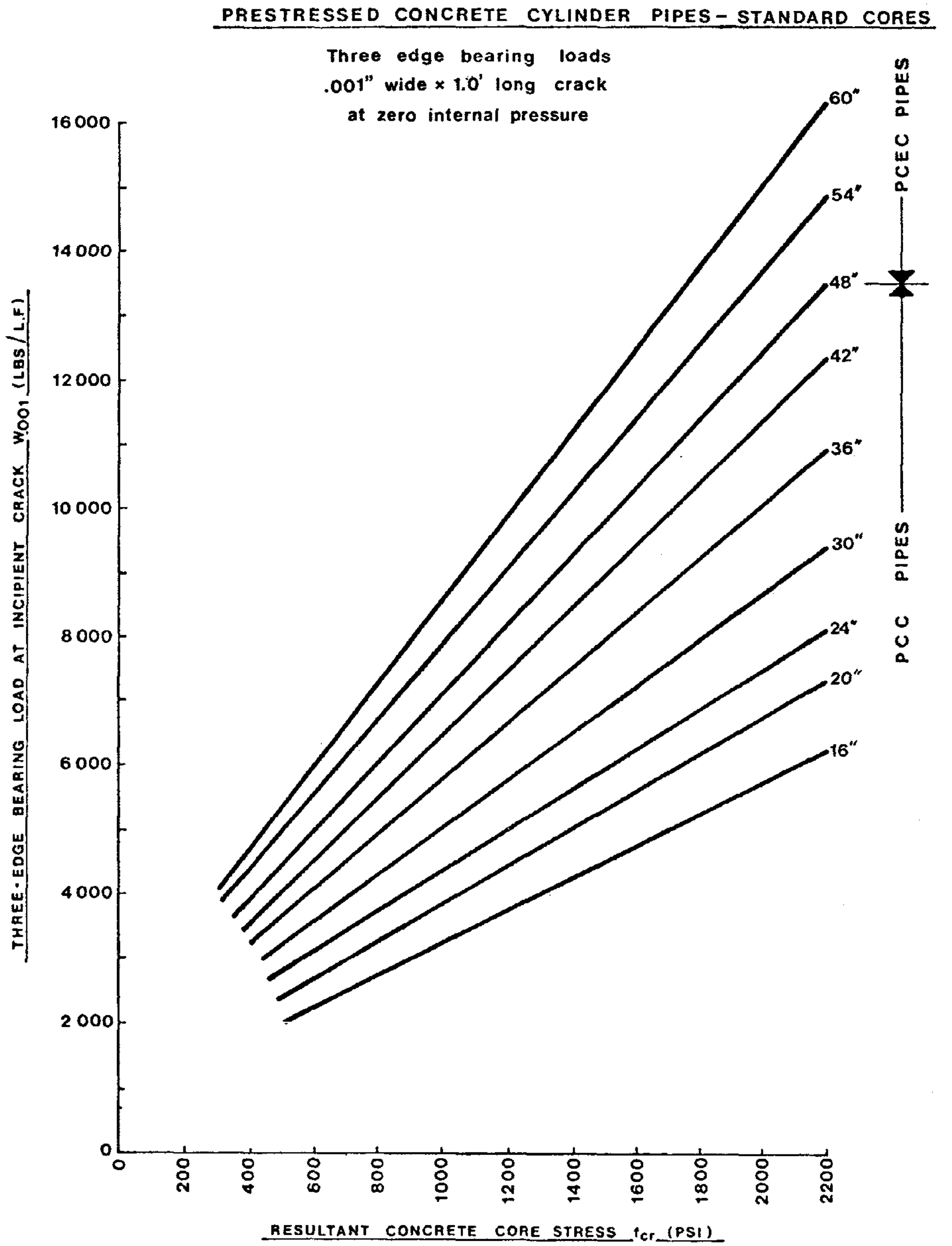


Fig. 22

EXAMPLE A

TYPICAL DESIGN OF A 30 IN. DIAMETER PRESTRESSED CONCRETE LINED CYLINDER PIPE (PCC)*

1. PIPE INPUT DATA:

Inner Diameter D	=	30 in.
Core Thickness t_c	=	1-7/8 in.
Coating Thickness t_{wc}	=	13/16 in.
Total Pipe Thickness t_w	=	2.6875 in.
Steel Cylinder Thickness t_y	=	0.0610 in.
Cylinder Area/L.f. of circumference A_y	=	0.7320 in.^{2}/L.f.
Outer Cylinder Diameter D_y	=	33.75 in.
$6\ D_y$	=	202.5 in.
Outer Diameter of Pipe O.D.	=	35.375 in.
Wrapping Wire gauge	=	No. 8
Wire Type (See Table X)	=	IV
Wire Diameter	=	0.162 in.
Area of wire/L.f. of circumference A_s	=	0.285 in.^{2}/l.f.
Area of core/L.f. of circumference A_c	=	21.768 in.^{2}/l.f.

DESIGN DATA:

For properties of the concrete core, steel cylinder and wrapping wire, see Tables IX and X (p. 112 and 113).

*This example is based on sample calculations of a major manufacturer.

3. LOADING DATA:

a) Depth of Earth Cover - H:

$H = 6$ ft.

b) Unit Weight of Earth - W_s:

$W_s = 120$ lbs./c.f.

c) Pipe Weight - W_p:

$W_p = 325$ lbs/L.f. from Table IV Part II

d) Water Weight - W_w (for full pipe):

$$W_w = \frac{\pi D^2}{4} \times \frac{1.0}{144} \times 62.4 \text{ pcf} = \frac{\pi (30.)^2 \times 62.4}{4 \times 144} = 306 \text{ lbs/l.f.}$$

e) Normal Operating Pressure - P_w:

$P_w = 150$ psi

f) Minimum Operating Pressure - P_{min}:

P_{min} = Pressure due to a 30' head of water = 13.0 psi

(Does not govern when negative pressures are considered)

g) Incremental Surge Pressure - ΔP_{sp}:

$\Delta P_{sp} = 0.40\ P_w = 0.40\ (150) = 60$ psi

(Surge Pressure = $P_s = P_w + \Delta P_{sp} = 150. + 60. = 210.$ psi)

h) Vacuum Pressure - P_{neg}:

$P_{neg} = -10$ psi

i) Traffic Load on Pipe - P:

Single wheel load for AASHO H-20 truck load = P = 16,000 lbs.

j) Seismic Pressure Intensity - P_{eg}:

$P_{eg} = W_{su}/B_c = 2.2$ kips/s.f.

W_{s_u} = Seismic Force/l.f. to pipe, and B_c = O.D. of pipe

4. ALLOWABLE STRESSES:

a) Initial Gross Wrapping Stress in Wire - f_{sg}:

$f_{sg} = 0.75\ f_{su} = 219{,}750$

(see Ref. 19, p. 11, and Table X)

b) Initial Concrete Core Compressive Stress - f_c:

$f_c \geq 3500$ psi (see Table IX)

c) Final Concrete Core Compressive Stresses - f_c:

(see Ref. 19, p.11)

$f_c = 0.45\ f_c' = 0.45 \times 6000 = 2700$ psi (steady state condition)

$f_c = 0.60\ f_c' = 0.60 \times 6000 = 3600$ psi (transient state condition)

d) Final Concrete Core Tensile Stress - f_t:

(see Part III, Subdivision 16)

$f_t = 7.5 \sqrt{f_c'} = 7.5\ (77.5) = 581$ psi (steady state condition)

$f_t = 10.5 \sqrt{f_c'} = 10.5\ (77.5) = 813$ psi (transient state condition)

5. PRESTRESSING STRESSES

a) Initial Concrete Core Compressive Stresses - f_{ci} (Ref. 19, p.8)

$$f_{ci} = \frac{A_{sfsg}\left(1-R_1-R_2\right)}{A_c+N_i(A_s+A_y)} =$$

$$\frac{0.285 \times 219750\ (1-0.05-0.)}{21.768 + 6(0.285+0.732)} = 2135 \text{ psi}$$

$f_{ci\ max}$ (for PCEC pipes) = 2250 psi (see Table IX)

$f_{ci} < f_{ci\ max}$ 2135 <2850 (see Table IX)

b) Initial Unit Stress in Wire - f_{si}:

$$f_{si} = f_{sg}\ (1-R_1-R_2) - N_i f_{ci}$$

= 219750 (1-0.05 - 0.) - 6(2135) = 195,954. psi

c) Resultant Concrete Core Stress After Relaxation and Creep Losses (Ref. 19, p.9):

$$f_{cr} = f_{ci}\ \left[\frac{A_c+N_r(A_s+A_y)}{A_c+N_r(A_s+A_y)\ (1+C_r)}\right] =$$

$$= 2135\ \left[\frac{21.77 + 5(0.285+0.732)}{21.77 + 5(0.285+0.732)\ (1+1.5)}\right] = 1663. \text{ psi}$$

d) Concrete Core Compressive Stresses at the Time of Wrapping - f_c:

$$f_c = \frac{f_{ci}}{0.55} = \frac{2135}{0.55} = 2882. \text{ psi} > 3200 \text{ (see Table IX, p.112).}$$

e) Resultant Wire Stress - f_{sr}: (Ref. 19, p.9):

$$f_{sr} = f_{si} - N_r\ [(1+C_r)\ f_{cr} - f_{ci}] =$$

= 195,954 - 5[(1+1.5) 1663 - 2135] = 185,842. psi

f) Cylinder Ring Stress - f_{yi}: (see Ref. 19, p.9 to p.81)
Initial Steel Cylinder Stress: =

$$f_{yi} = N_i f_{ci} = 6 \times 2135 = 12{,}810.\ \text{psi}$$

g) Resultant Steel Cylinder Ring Stress - f_{yr}: (see Ref. 19, p.9)

$$f_{yr} = f_{yi} + N_r\ [(1+C_r)f_{cr} - f_{ci} =$$

$$= 12{,}810. + 5[(1+1.5)1663-2135] = 22{,}923\ \text{psi} < f_{yb} = 41{,}000$$ (see Table IX,p.112).

6. <u>INTERNAL PRESSURE CRITERIA:</u>

a) Balancing Pressure - P_o (see nomenclature, p. 110)

$$P_o = \frac{f_{cr}}{6D_y}[A_c+N_r(A_s+A_y)] =$$ (see Ref. 19, p.10)

$$= \frac{1663}{202.5}[21.768 + 5(0.285 + 0.7320] = 220.5 \text{ psi}$$ (see fig. 20, p.114)

b) <u>Bursting Pressure - P_b (see nomenclature p. 110)</u>

$$P_b = \frac{f_{su}A_s+f_{yb}A_y}{6D_y}$$ (see Ref. 19, p.10)

$$= \frac{293000 \times 0.2850 + 41{,}000 \times 0.7320}{202.5} = 560.6 \text{ psi}$$ (see Fig. 20)

c) <u>Elastic Limit Pressure = P_L (see nomenclature, p. 110)</u>

$1.70\ P_w = 1.7 \times 150 = 255$ psi (see Fig. 20, p. 114)

$$P_L = \frac{f_{sg}}{6D_y}[A_s + A_y\ (R_1+R_2)] \geq 1.70\ P_w$$

$$= \frac{219750}{202.5}[0.2850+0.7320\ (0.05+0)] = 349 > 255 \text{ psi}$$

7. <u>EARTH LOADING ON PIPE</u>

a) Trench Width - B_d =

O.D. of pipe = B_c = D + 2 (core thickness) + 2 (Coating thickness)

$$B_c = 30'' + 2\ (1.875'') + 2\ (\frac{13''}{16})$$

B_c = 35.375 in. = <u>2.95 ft.</u>

$B_d = B_c + 2$ ft.

B_d = 2.95 ft. + 2 ft.

B_d = <u>4.95 ft.</u>

b) Transition Width: As the width of the ditch increases, other factors remaining constant, the load on a rigid conduit increases in accordance with the theory for a ditch conduit until it equals the load determined by the theory for a projecting conduit. The trench width at which this load equality develops is called the Transition Width (T.W.)

For $k\mu = 0.19$, $r_{sd} = 0.50$, and $w = 120$ lbs/c.f.

T.W. = 5'-1".....American Concrete Pipe Association Design (see Ref. 20,p.114)

where k = Rankine's ratio

μ = coefficient of internal friction of the backfill material

r_{sd} = settlement ratio (see Ref.20)

p = projection ratio (see Ref.20)

w = soil density

Since the ditch width B_d, is less than the transition width T.W., the earth loading should be designed as a trench loading.

c) Trench Load Coefficient - C_d:

$$C_d = \frac{1-e^{-2k\mu' \frac{H}{B_d}}}{2k\mu'}$$

where μ'= Coefficient of sliding friction between the backfill material and trench walls.

$k\mu' = .110$ (for saturated clay)

and H = height of cover over pipe = 6 ft.

$$C_d = \frac{1-e^{-2(0.110)\left(6/4.95\right)}}{2(0.110)} = 1.07$$

d) Trench Load $-W_e$:

$W_e = C_d \; W \; B_d^{\;2}$ (see Ref. 20, p.25)

$= (1.07)(120 \text{ lbs./ft.}^3)\ (4.95 \text{ ft.})^2$

$=$ 3146 lbs./l.f.

8. TRAFFIC LOADING ON PIPE

H-20 Live Load @ 6 ft. Cover

$W_{LL} = C_1 \; P \; (1+I)$ (Ref. 42)

W_{LL} = Live Load on Pipe

C_1 = Live Load Coefficient

= .03 (Ref. 42)

P = Single Wheel Load = 16,000 lbs. (see Ref. 20,p.33)

I = Impact Factor = 0% for 6 ft. cover assuming a gravel surfaced roadway

$\therefore W_{LL} = (.03)\ (16{,}000)(1+0)$

= 480 lbs./l.f.

9. SEISMIC LOADING ON PIPE

Seismic pressure = P_{eq} = 2.2 kips/s.f.

$W_{su} = P_{eq} \times B_c = 2.2 \times 2.95' = 6490$ lbs/L.f.

10. SUMMARY OF INDIVIDUAL LOADS:

1. Pipe Weight = W_p = 325 lbs/L.f.

2. Water Weight = W_w = 306 lbs/L.f.

3. Earth Cover = W_e = 3146 lbs/L.f.

4. Operating Pressure = P_w = 150 psi

5. Vacuum Pressure = P_v = -10 psi

6. Incremental Pressure due to surge = ΔP_{sp} = 60 psi

7. Traffic Loading = W_{LL} = 480 lbs/L.f.

8. Seismic Loading = W_{su} = 6490 lbs/L.f.

11. PROPERTIES OF COMPOSITE PIPE:

a)

COMPOSITE SECTION WITH CONCRETE PROTECTIVE COATING

(USE AT CROWN AND INVERT FOR ALL LOADINGS EXCEPT SEISMIC)

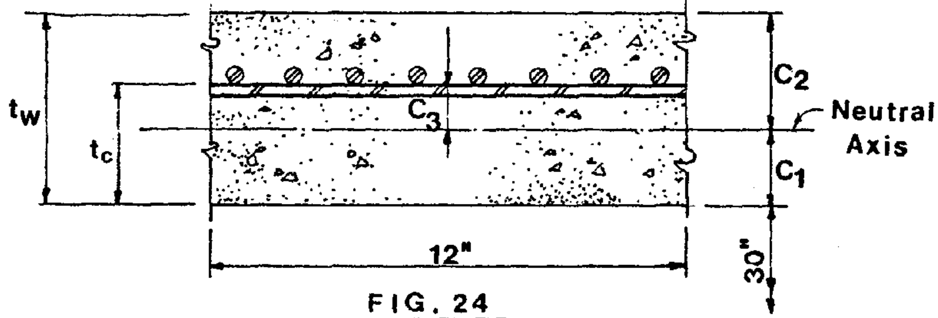


FIG. 24

ELEMENTS	AREA ×	ARM =	AREA MOMENT
CONCRETE	$12\,t_w = 32.25$	$\frac{t_w}{2} = 1.34375$	43.336
CYLINDER	$(n_r - 1)\,A_y = 2.928$	$t_c = 1.875$ *	5.49
WIRE	$(n_r - 1)\,A_s = 1.14$	$t_c = 1.875$	2.1375
TRANSFORMED AREA	$\Sigma A = 36.318$		$\Sigma M = 50.9635$

Location of neutral axis:

$$C_1 = \frac{\Sigma M}{\Sigma A} = \frac{50.9635}{36.318} = 1.40 \text{ in.}$$

$$C_2 = t_w - C_1 = 1.2865 \text{ in.}$$

$$C_3 = C_2 - .875 = 0.4115 \text{ in.}$$

Moment of Inertia about neutral axis

$$I = \frac{12}{3}\,(C_1{}^3 + C_2{}^3) + (n_r - 1)\,(A_y\,C_3{}^2) + (n_r - 1)\,(A_s)\,(C_3)^2 = 20.21 \text{ in.}^4/\text{l.f}$$

Section Modulus of the Cross section about neutral axis

$$S = \frac{I}{C_1} = 14.42 \text{ in.}^3/\text{l.f. inside of pipe}$$

$$S = \frac{I}{C_3} = 49.11 \text{ in.}^3/\text{l.f. at face of core}$$

$$S = \frac{I}{C_2} = \frac{20.21 \text{ in.}^4/\text{l.f.}}{1.2865 \text{ in.}} = 15.71 \text{ in.}^3/\text{l.f. at extreme fiber}$$

Total Area

$$A_{t_1} = \Sigma A = 36.318 \text{ in.}^2/\text{l.f.}$$

b)

COMPOSITE SECTION
WITH CRACKED PROTECTIVE COATING

(USE AT SPRINGLINE FOR ALL LOADINGS EXCEPT SEISMIC)

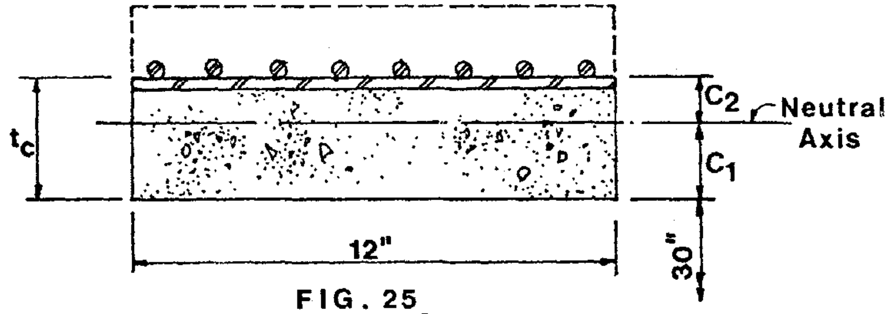


FIG. 25

ELEMENTS	AREA ×	ARM =	AREA MOMENT
CONCRETE	$12 t_c = 22.50$	$t_c/2 = .9375$	21.094
CYLINDER	$(n_r - 1) A_y = 2.928$	$t_c = 1.875$ *	5.49
WIRE	$n_r A_s = 1.425$	$t_c = 1.875$	2.672
TRANSFORMED AREA	$\Sigma A = 26.853$		$\Sigma M = 29.256$

*Using the outside diameter of the cylinder gives results which are accurate and have been verified experimentally (Ref. 43, p. 54)

Location of neutral axis

$$C_1 = \frac{\Sigma M}{\Sigma A} = \frac{29.256}{26.853} = 1.09 \text{ in.}$$

$$C_2 = t_c - C_1 = .785 \text{ in.}$$

Moment of Inertia about neutral axis

$$I = \frac{12}{3}(C_1^3 + C_2^3) + (n_r - 1)(A_y C_2^2) + (n_r A_s C_2^2) = 9.798 \text{ in.}^4/\text{l.f.}$$

Section Modulus of Cross section about neutral axis

$$S = \frac{I}{C_2} = 12.481 \text{ in.}^3/\text{l.f. at face of core}$$

$$S = \frac{I}{C_1} = \frac{9.798 \text{ in.}^4/\text{l.f.}}{1.09 \text{ in.}} = 8.99 \text{ in.}^3/\text{l.f. inside of pipe}$$

Total Area

$$A_{t_2} = 26.853 \text{ in.}^2/\text{l.f.}$$

WORKING STRESS DESIGN METHOD:

a) Loading Conditions

L.C. (1) - Earth Load + Pipe Load + Vacuum Pressure

L.C. (2) - Earth Load + Pipe Load + Water Load + Design Pressure

L.C. (3) - L.C. 2 + Incremental Pressure Due to Surge

L.C. (4) - L.C. 2 + Traffic Loading

L.C. (5) - L.C. 2 + Traffic Loading + Seismic Loading

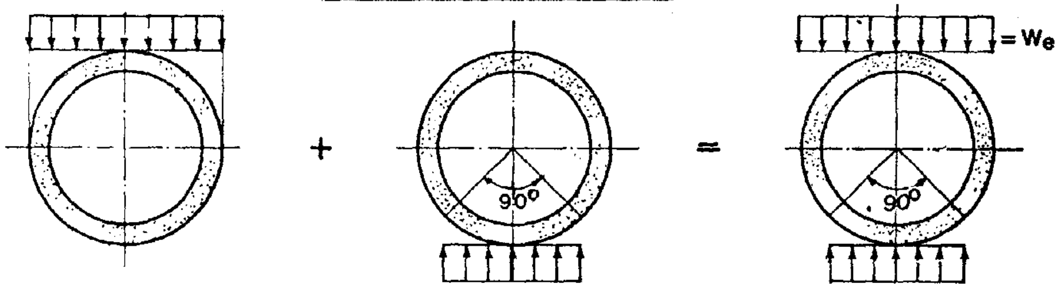
L.C. (6) - L.C. 1 + Traffic Loading

L.C. (7) - L.C. 1 + Traffic Loading + Seismic Loading

L.C. denotes Loading Condition

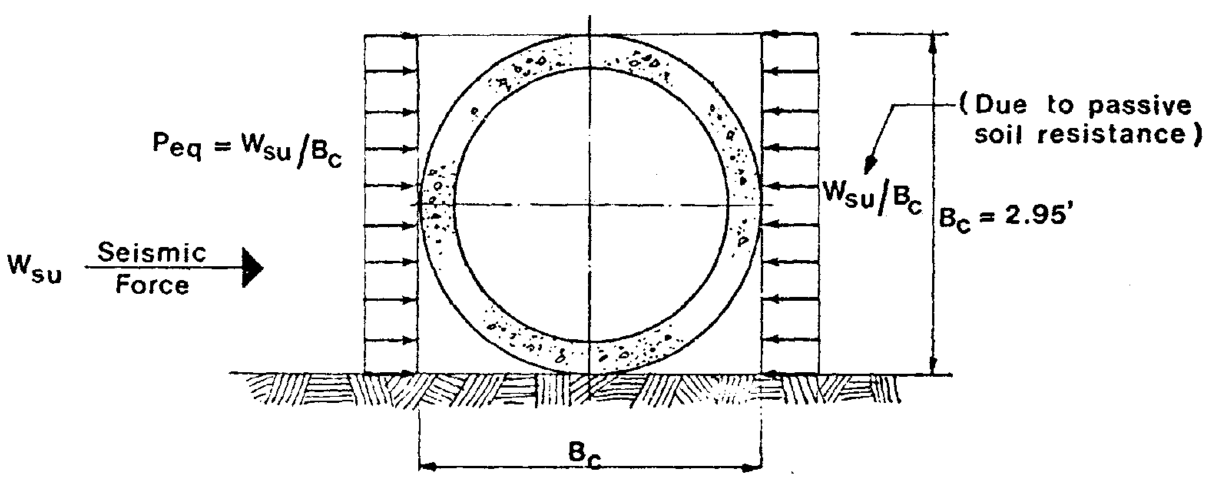
b) RING MODELS AND MEAN RADII

BEDDING ANGLE - 90°



PIPE RING MODEL FOR EARTH AND TRAFFIC LOADINGS

Fig. 26 A



PIPE RING MODEL FOR SEISMIC FORCE

Fig. 26 B

MEAN RADIUS OF PIPE = R

At Invert & Crown $R = (D+t_w)/24$ (ft.)

At Springline $R = (D+t_c)/24$ (ft.)

12c)

GENERAL FORMULAS FOR THRUST AND MOMENT		
LOADING COMPONENTS	THRUST (lbs./ft.)	MOMENT (ft.-lbs./ft.)
PIPE WEIGHT	$F_p = C_2 W_p$	$M_p = C_4 W_p R$
WATER WEIGHT	$F_w = C_5 W_w$	$M_w = C_6 W_w R$
EARTH COVER	$F_e = C_1 W_e$	$M_e = C_2 W_e R$
INTERNAL PRESSURE-HOOP FORCE	$F_h = C_9 P$	——
SEISMIC LOADING	$F_{su} = C_7 W_{su}$	$M_{su} = C_8 W_{su} R$

TABLE XI

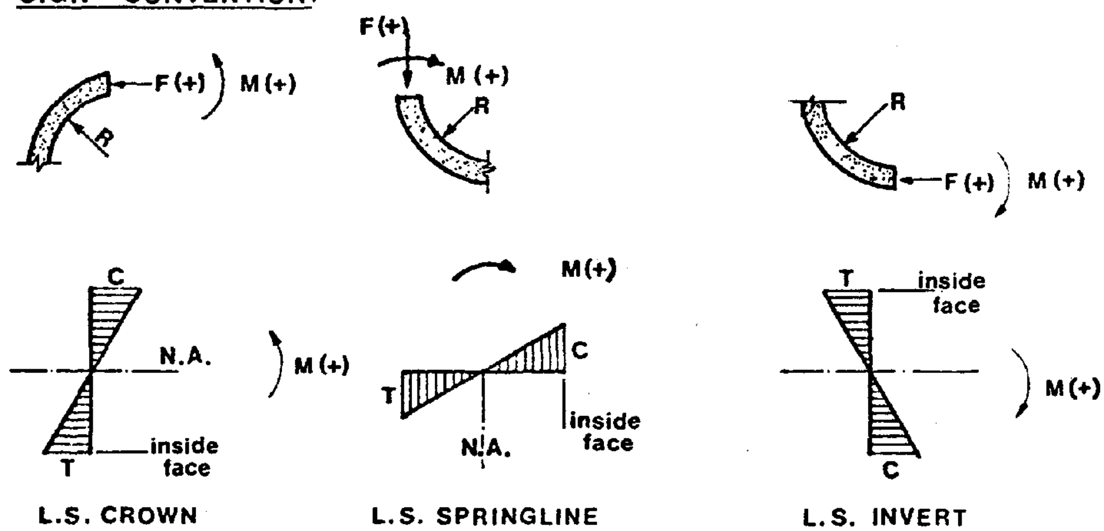
12d)

FORCE AND MOMENT COEFFICIENTS						
LOADING	CROWN		SPRINGLINE		INVERT	
	THRUST	MOMENTS	THRUST	MOMENTS	THRUST	MOMENTS
PIPE WEIGHT	$C_1 = 0.053$	$C_3 = 0.067$	$C_1 = 0.25$	$C_3 = 0.077$	$C_1 = 0.053$	$C_3 = 0.102$
WATER WEIGHT	$C_2 = 0.212$	$C_4 = 0.067$	$C_2 = 0.068$	$C_4 = 0.077$	$C_2 = 0.408$	$C_4 = 0.102$
EARTH COVER AND TRAFFIC	$C_5 = 0.027$	$C_6 = 0.137$	$C_5 = 0.500$	$C_6 = 0.140$	$C_5 = 0.027$	$C_6 = 0.157$
* INTERNAL PRESSURE	$C_9 = 202.5$	——	$C_9 = 202.5$	——	$C_9 = 202.5$	——
SEISMIC	$C_7 = 0.500$	$C_8 = 0.125$	$C_7 = 0.0$	$C_8 = 0.125$	$C_7 = 0.500$	$C_8 = 0.125$

TABLE XII

* Internal pressure may be a working pressure, incremental pressure due to surge, or a vacuum pressure (negative).

12e) SIGN CONVENTION:



SIGN CONVENTION FOR FORCES AND STRESSES

L.S.-Denotes left side.
(+) -Denotes compression.
(-) -Denotes tension.

FIG. 27

12d) Force and Moment Coefficients:

Two kinds of force coefficients are generally used by industry in determining the thrusts and moments for points on the pipe. The first of these are coefficients for large horizontal pipes developed by J.M. Paris in 1921 (see Ref. 45, p.768). The second are coefficients arrived at by H.C. Olander in 195 (see Ref. 18, p.10 and Ref. 19, p.15). For a discussion of methodologies in determining these coefficients, and an explanation of the differences in the values of thrust and moment obtained from each, see Section IV 3C.

In Table XII following, C_1 to C_8 are the force coefficients for circular pipes by Paris, and C_9 is the force coefficient for the hoop force in the ring = $12D_y/2 = 6D_y$.

12f)

THRUSTS AND MOMENTS DUE TO LOADING COMPONENTS							
LOADING COMPONENTS		CROWN		SPRINGLINE		INVERT	
		THRUST (lbs./ft.)	MOMENT (ft.-lbs./ft.)	THRUST (lbs./ft.)	MOMENT (ft.-lbs./ft.)	THRUST (lbs./ft.)	MOMENT (ft.-lbs./ft.)
A	PIPE WEIGHT	-17.23	29.65	81.25	34.08	17.23	45.15
B	WATER WEIGHT	-64.87	27.92	-20.81	32.09	-124.85	42.51
C	EARTH COVER	-84.94	586.16	1573.0	599.0	84.94	671.73
D	INTERNAL PRESSURE-HOOP FORCE	-30375.	——	-30375.	——	-30375.	——
E	VACUUM PRESSURE	2025.	——	2025.	——	2025.	——
F	INCREMENTAL PRESSURE DUE TO SURGE	-12150.	——	-12150.	——	-12150.	——
G	TRAFFIC LOADING	-12.96	89.44	240.0	91.39	12.96	102.49
H	SEISMIC LOADING	3245.	-1103.3	0.	-1103.3	3245.0	-1103.3

TABLE XIII

12g)

STRESSES DUE TO LOADING COMPONENTS-Δf_{crl} (psi)										
LOADING COMPONENTS		CROWN			SPRINGLINE			INVERT		
		THRUST-F/A	MOMENT-M/S		THRUST-F/A	MOMENT-M/S		THRUST-F/A	MOMENT-M/S	
			I.F.	O.F.		I.F.	O.F.		I.F.	O.F.
A	PIPE WEIGHT	-1	-25	7	3	45	-33	1	-38	11
B	WATER WEIGHT	-2	-23	7	-1	43	-31	-3	-35	10
C	EARTH COVER	-2	-488	143	59	800	-578	2	-559	164
D	INTERNAL PRESSURE-HOOP STRESS	-836	——	——	-1131	——	——	-836	——	——
E	VACUUM PRESSURE	56	——	——	75	——	——	56	——	——
F	INCREMENTAL PRESSURE DUE TO SURGE	-335	——	——	-453	——	——	-335	——	——
G	TRAFFIC LOADING	——	-75	22	9	122	-88	——	-85	25
H	SEISMIC LOADING *	121	918	-270	——	-1473	1061	121	918	-270

TABLE XIV

Notes:

* For seismic loading the invert is considered cracked, and the springline uncracked.

SIGN CONVENTION:

Minus sign (-) denotes tension.
No sign (positive value) denotes compression.

I.F.- Inner face of pipe.
O.F.- Outer face of pipe.

12h) Summations for Critical Stresses from Loading Conditions

For each of the loading conditions outlined in the flowchart for the final design of water pipe line, (Fig. 19), there is a resultant internal core stress change due to the internal and external loads. Therefore, for any loading condition the resultant core stress change Δf_{cr} due to the corresponding loading components equals the summation of the Δf_{cr} due to each loading component.

The resultant core stress changes Δf_{cr} combined with the precompression core stress f_{cr} (due to prestressing) gives the net core resultant stress, f_{ncr} = for each loading condition. The f_{ncr}'s must be compared with the allowable working stresses defined by the stress analysis design method of AWWA Standard C301, (see Part III subdivision 16).

In order to obtain a summation for the Δf_{cr}'s, add all the values for the loading components and combination of loading conditions from left to right in any row of Tables XV to XXI. The values for the f_{cr}'s are shown in the second column from the extreme right of the table. The final right-hand column shows the final net core stresses - f_{crn}'s for points on the pipe for a given loading condition, when the precompression core stress f_{cr} due to prestressing is added to these summations.

12h)

SUMMATION OF STRESSES – LOADING CONDITION 1									
STRESS LOCATION / LOADING		A – PIPE WEIGHT STRESSES (psi)		C – EARTH COVER STRESSES (psi)		E – VACUUM PRESSURE STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST	MOMENT	THRUST	MOMENT	THRUST	MOMENT		
CROWN	I. F.	−1	−25	−2	−488	56	—	−460	1203
	O.F.	−1	7	−2	143	56	—	203	1866
SPRINGLINE	I. F.	3	45	59	800	75	—	982	2645
	O.F.	3	−33	59	−576	75	—	−507	1156
INVERT	I. F.	1	−38	2	−559	56	—	−538	1125
	O. F.	1	11	2	164	56	—	234	1897

TABLE XV

SUMMATION OF STRESSES – LOADING CONDITION 2											
STRESS LOCATION / LOADING		A – PIPE WEIGHT STRESSES (psi)		B – WATER WEIGHT STRESSES (psi)		C – EARTH COVER STRESSES (psi)		D – INTERNAL PRESSURE-HOOP STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST	MOMENT	THRUST	MOMENT	THRUST	MOMENT	THRUST	MOMENT		
CROWN	I. F.	−1	−25	−2	−23	−2	−488	−836	—	−1377	286
	O.F.	−1	7	−2	7	−2	143	−836	—	−684	979
SPRINGLINE	I. F.	3	45	−1	43	59	800	−1131	—	−182	1481
	O.F.	3	−33	−1	−31	59	−576	−1131	—	−1710	−47
INVERT	I. F.	1	−38	−3	−35	2	−559	−836	—	−1468	195
	O. F.	1	11	−3	10	2	164	−836	—	−651	1012

TABLE XVI

SUMMATION OF STRESSES – LOADING CONDITION 3						
STRESS LOCATION / LOADING		L.C. (2) STRESSES (psi)	D – INCREMENTAL HOOP STRESS DUE TO SURGE (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST + MOMENT	THRUST	MOMENT		
CROWN	I. F.	−1377	−335	—	−1712	− 49
	O.F.	− 684	−335	—	−1019	644
SPRINGLINE	I. F.	− 182	−453	—	− 635	1028
	O.F.	−1710	−453	—	−2163	− 500
INVERT	I. F.	−1468	−335	—	−1803	− 140
	O. F.	− 651	−335	—	− 986	677

TABLE XVII

12h)

SUMMATION OF STRESSES - LOADING CONDITION 4						
STRESS LOCATION \ LOADING		L.C. (2) STRESSES (psi)	G - TRAFFIC STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST+MOMENT	THRUST	MOMENT		
CROWN	I. F.	- 1377	0	- 75	- 1452	211
	O.F.	- 684	0	22	- 662	1001
SPRINGLINE	I. F.	- 182	9	122	- 51	1612
	O.F.	- 1710	9	- 88	- 1789	- 126
INVERT	I. F.	- 1468	0	- 85	- 1553	110
	O. F.	- 651	0	25	- 626	1037

TABLE XVIII

SUMMATION OF STRESSES - LOADING CONDITION 5								
STRESS LOCATION \ LOADING		L.C. (2) STRESSES (psi)	G-TRAFFIC STRESSES (psi)		H-SEISMIC STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST+MOMENT	THRUST	MOMENT	THRUST	MOMENT		
CROWN	I. F.	-1377	0	-75	121	918	-413	1250
	O.F.	-684	0	22	121	-270	-811	852
SPRINGLINE	I. F.	- 182	9	122	0	-1473	-1524	139
	O.F.	-1710	9	-88	0	1061	-728	935
INVERT	I. F.	-1468	0	-85	121	918	-514	1149
	O. F.	-651	0	25	121	-270	-775	888

TABLE XIX

SUMMATION OF STRESSES - LOADING CONDITION 6						
STRESS LOCATION \ LOADING		L.C. (1) STRESSES (psi)	G - TRAFFIC STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST+MOMENT	THRUST	MOMENT		
CROWN	I. F.	-460	0	-75	- 535	1128
	O.F.	203	0	22	225	1888
SPRINGLINE	I. F.	982	9	122	1113	2776
	O.F.	- 507	9	-88	- 586	1077
INVERT	I. F.	- 538	0	-85	- 623	1040
	O. F.	234	0	25	259	1922

TABLE XX

12h)

SUMMATION OF STRESSES – LOADING CONDITION 7								
STRESS LOCATION \ LOADING		L.C. (1) STRESSES (psi)	G – TRAFFIC STRESSES (psi)		H – SEISMIC STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST+MOMENT	THRUST	MOMENT	THRUST	MOMENT		
CROWN	I. F.	– 460	0	– 75	121	918	504	2167
	O.F.	203	0	22	121	– 270	76	1739
SPRINGLINE	I. F.	982	9	122	0	–1472	– 359	1304
	O.F.	– 507	9	– 88	0	1061	475	2138
INVERT	I. F.	– 538	0	– 85	121	918	416	2079
	O. F.	234	0	25	121	– 270	110	1773

TABLE XXI

CRITICAL CONDITIONS:

Loading Condition (1) - Springline I.F.

2645 psi <2700 psi o.k. (see p.119)

Loading Condition (6) - I.F. at Springline

2776 psi <3600 psi (see p.119)

Loading Condition(3) - Springline O.F.

500 psi <813 psi o.k. (see p.119)

12i) Maximum Operating Pressure and Earth Cover:

Based on the preceding critical conditions the following limits on the internal pressure and the earth cover are obtained:

For maximum tension (at O.F. springline)

$$\Sigma F = F_{pipe} + F_{water} + F_{earth} = 81-21+1573 = 1633 \text{ lbs/ft.}$$

$$\Sigma M = M_{pipe} + M_{water} + M_{earth} = 34+32+599 = 665 \text{ ft-lbs/ft.}$$

$$P_{max} = \left[f_{cr} + K\ f'_c + \frac{\Sigma F}{A_t} - \frac{\Sigma M}{S} \right] \frac{A_t}{12R_y}$$

(see Part III Subdivision 16)

$$= \left[1663 + 10.5\sqrt{6000} + \frac{1633}{26.65} - \frac{665\text{x}12}{12.48} \right] \frac{26.85}{202.5} = 252 \text{ psi}$$

$$1.4\ P_w = 210 \text{ psi}, \qquad P_{wmax} = 246/_{1.4} = 176 \text{ psi} > P_{w\,allowable}$$

For maximum compression (at I.F. springline)

$$\Sigma F = F_{pipe} + F_{vac.} + F_{earth} = 81 + 2025 + 1573 = 3679 \text{ lbs/ft.}$$

$$\Sigma M = M_{pipe} + M_{vac.} + M_{earth} = 34 + 0 + 599 = 633 \text{ ft-lbs/ft.}$$

$$W_{dmax} = \frac{A_t Skf'c + S(12R_y)\ P_w - [A_t S_{fcr} + S(\Sigma F - F_{earth}) + A_t(\Sigma M - M_{earth})]}{C_6\ R_m\ A_t + C_s S} =$$

(See Ref. 19, p.10)

$$= \frac{26.85 \text{ x } 8.99 \text{ x } 0.45 \text{ x } 6000 + 8.99 \text{ x } 202.5 \text{ x } 10 - [26.85 \text{ x } 8.99 \text{ x } 1663 +}{0.140 \text{ x } 15.94 \text{ x } 26.85 +}$$

$$\frac{+8.99 \text{ x } 2106 + 26.85 \text{ x}(34.12)]}{+0.500 \text{ x } 8.99} = 3704 \text{ lbs}/_{\text{Lin.ft.}}$$

$$C_d = \frac{W_{dmax}}{\gamma_e \text{ x } B_d^2} = \frac{3704}{120\text{x}4.95^2} = 1.26$$

$$H_{max} = \frac{\ln(1-C_d 2K_\mu') \text{ x } B_d}{-2K_\mu'} = \frac{\ln(1-1.26\text{x}2\text{x}0.11)\text{x}4.95}{-2\text{x}0.11} = 7.3 \text{ ft.}$$

13. CRACK CONTROL CALCULATIONS

a) Class "B" Bedding p Load Factor = 1.9

Class "D" Bedding - Load Factor = 1.1

b) Allowable three-edge-bearing-load at P_w:

f_{cr} = 1663 psi

Maximum three-edge bearing load for 0.001 crack at P=0

= $W_{.001}$ = 7400 lbs/lin.foot (see Fig. 28)

$W_o = 0.9 \times W_{.001} = 0.9 \times 7400 = 6660$ lbs/lin.ft.

P_o = 220 psi (see p.71)

$0.8\ P_o = 0.8 \times 220 = 176$ psi (see Part III Subdivision 15)

$P_w = 150 < 176$

$P_s = P_w + \Delta P_{sp} = 210 < 1.4 P_o$

From Cubic Parabola Interaction Curve (see Fig. 29)

For $P_w = 150$, $W_w = 0.684 \times 6660 = 4555$ lbs/lin.ft.

c) Equivalent three-edge-bearing load

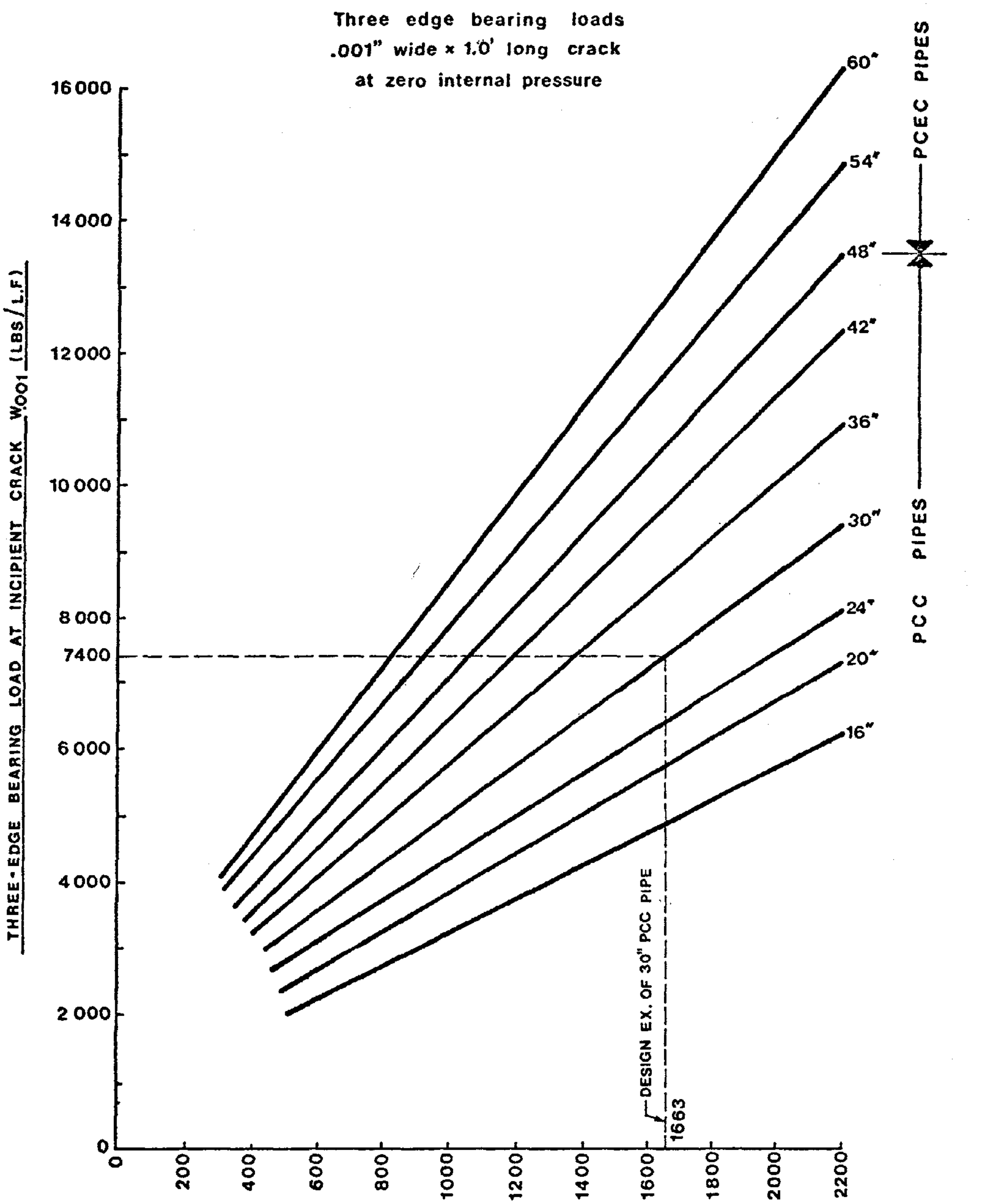
For Class "B" Bedding: W/L_f = 3146/1.9 = 1656 lbs/l.f. <4555 lbs/l.f. (allowable, see fig. 29)

For Class "D" Bedding: W/L_f = 3146/1.1 = 2860 lbs/l.f. <4555 lbs/l.f. (allowable, see fig. 29)

PART IV 5

THREE-EDGE BEARING LOAD vs. RESULTANT CONC. CORE STRESS

PRESTRESSED CONCRETE CYLINDER PIPES – STANDARD CORES



RESULTANT CONCRETE CORE STRESS f_{cr} (PSI)

FIG. 28

PART IV. 5

PLOT OF CUBIC PARABOLA INTERACTION

FORMULA OF AWWA C 301 $W = W_O \sqrt[3]{\frac{P_O - P}{P_O}}$
FOR COMBINED STRESSES
FROM 3-EDGE BEARING AND INTERNAL PRESSURE
FOR PRESTRESSED CONCRETE CYLINDER PIPE—PCC
AND PRESTRESSED CONCRETE EMBEDDED CYLINDER—PCEC

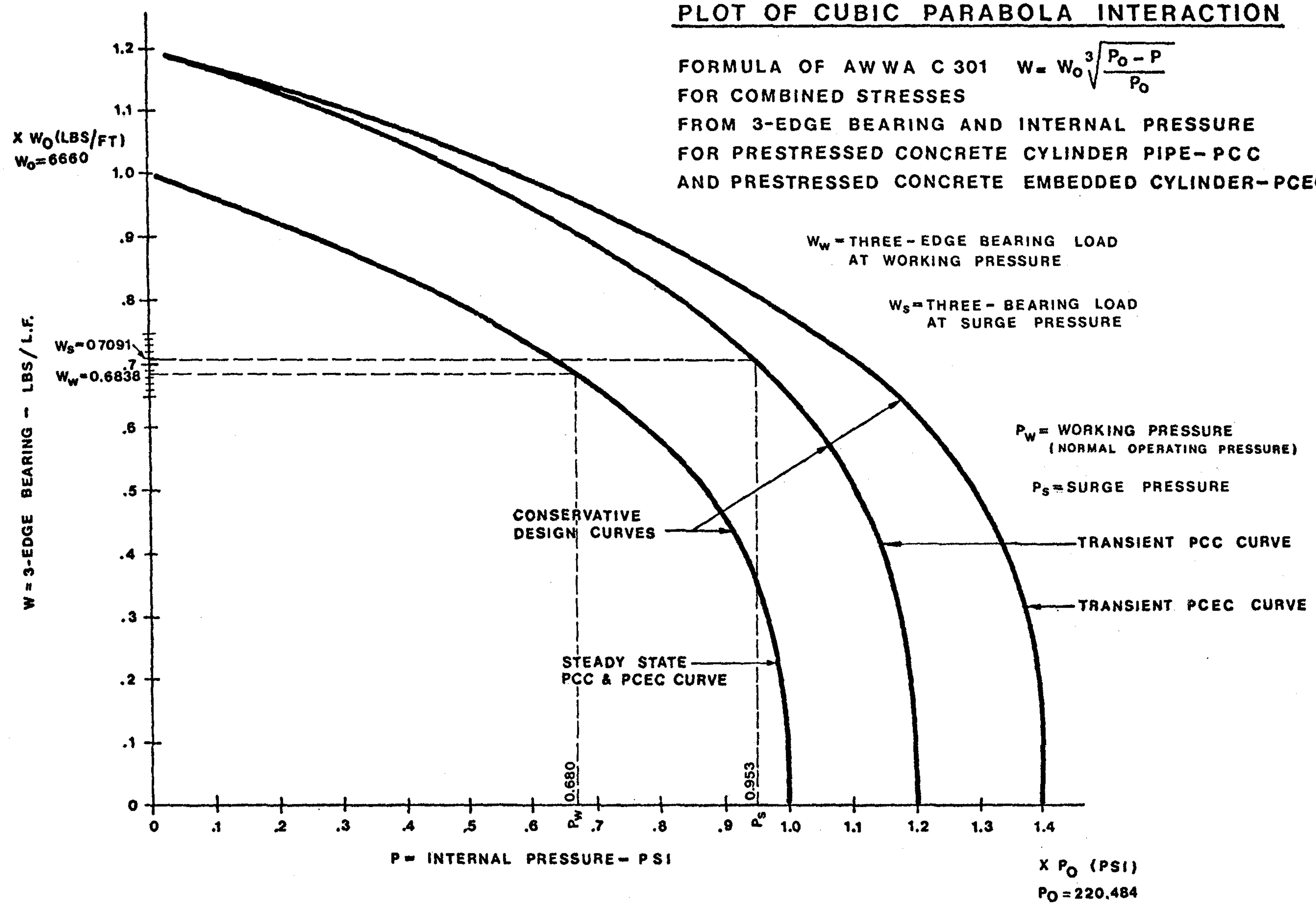


FIG. 29

EXAMPLE B

TYPICAL DESIGN OF A 60 IN. DIAMETER PRESTRESSED CONCRETE EMBEDDED CYLINDER PIPE (PCEC)*

PIPE INPUT DATA:

Inner Diameter D	= 60 in.
Core thickness t_c	= 4-1/2 in.
Coating thickness t_{wc}	= 7/8 in.
Total pipe thickness t_w	= 5.375 in.
Steel cylinder thickness t_y	= 0.0598 in.
Cylinder area/l.f. of curcumference A_y	= 0.7176 in^2/l.f.
Outer cylinder diameter D_y	= 63.0 in.
6 D_y	= 378.0 in.
Outer diameter of pipe O.D.	= 70.75 in.
Wrapping wire gauge	= No. 8
Wire type (see Table X)	= IV
Wire diameter	= 0.162 in.
Area of wire/l.f. of circumference A_s	= 0.5586 in^2/l.f.
Area of core/l.f. of circumference A_c	= 53.282

Design Data:

For properties of the concrete core, steel cylinder and wrapping wire, see Tables IX and X (p.112 and 113).

*This example is based on a computer run for a 60"PCEC pipe by a major manufacturer.

LOADING DATA:

Depth of Earth Cover - H:

H = 8 ft.

Unit Weight of Earth - W_s:

W_s = 120 lbs/c.f.

Pipe Weight - W_p:

W_p = 1200 lbs/l.f. from Table V Part II

Water Weight - W_w (for full pipe):

$$W_w = \frac{\pi D^2}{4} \times \frac{1.0}{144} \times 62.4 \text{ pcf} = \frac{\pi (60.)^2 x 62.4}{4x144} = 1225 \text{ lbs/l.f.}$$

Normal Operating Pressure - P_w:

P_w = 150 psi

Minimum Operating Pressure - P_{min}:

P_{min} = Pressure due to a 30' head of water = 13.0 psi
(Does not govern when negative pressures are considered)

Incremental Surge Pressure - ΔP_{sp} = 0.40 P_w = 0.40 (150) = 60 psi
(surge pressure = P_s = $P_w + \Delta P_{sp}$ = 150.+60. = 210. psi)

Vacuum Pressure - P_{neg}:

P_{neg} = -10 psi

Traffic load on pipe -P:
Single wheel load for AASHO H-20 truck load = P = 16000 lbs.

Seismic Pressure Intensity - P_{eg}:

P_{eg} = W_{su}/B_c = 2.2 kips/s.f.

W_{su} = seismic force/l.f. to pipe, and B_c = O.D. of pipe

ALLOWABLE STRESSES:

1. Initial gross wrapping stress in wire - f_{sg} :

$f_{sg} = 0.75\ f_{su} = 219{,}750$ (see ref. 19, p. 11, and Table X)

2. Initial concrete core compressive stress - f_c:

$f_{ci\ min.} \geq 3200$ psi (see Table IX)

3. Final concrete core compressive stresses - f_c:

(see ref. 19, p.11)

$f_c = 0.45\ f_c = 0.45 \times 5000 = 2250$ psi (steady state condition)

$f_c = 0.60\ f_c' = 0.60 \times 5000 = 3000$ psi (transient state condition)

4. Final concrete core tensile stress - f_t:

(see Part III, subdivision 16)

$f_t = 7.5 \quad f_c' = 7.5\ (70.7) = 530$ psi (steady state condition)

$f_t = 10.5 \quad f_c' = 10.5\ (70.7) = 743$ psi (transient state condition)

5. Prestressing stresses

a) Initial concrete core compressive stress - f_{ci} (ref. 19, p.8)

$$f_{ci} = \frac{A_s f_{sg}(1-R_1-R_2)}{A_c + n_i(A_s+A_y)} =$$

$$= \frac{0.5586 \times 219750(1-0.05-0.05)}{53.28 + 7(0.5586+0.7176)} = 1775.7 \text{ psi}$$

$f_{ci\ max}$ (for PCEC pipes) = 2250 spi (see Table IX)

$f_{ci} < f_{ci\ max} \quad 1776 < 2250$ (see Table IX)

b) Initial unit stress in wire - f_{si}:

$$f_{si} = f_{sg}(1-R_1-R_2) - N_i f_{ci}$$

$$= 219750\ (1-0.05-0.05) - 7(1775.7) = 185{,}345 \text{ psi}$$

c) Resultant concrete core stress after relaxation and creep losses

(Ref. 19, p.9):

$$f_{cr} = f_{ci}\left[\frac{A_c + N_r(A_s+A_y)}{A_c+N_r(A_s+A_y)(1+C_r)}\right] =$$

$$= 1788\left[\frac{53.28 + 6(0.5586+0.7176)}{53.28 + 6(0.5586+0.7176)(1-2.0)}\right] = 1419 \text{ psi}$$

d) Concrete core compressive stresses at the time of wrapping: (see Table IX)

$$f_c = \frac{f_{ci}}{0.55} = \frac{1776}{0.55} = 3229 \text{ psi} > 3200 \text{ (see Table IX, p. 112)}$$

e) Resultant wire stress - f_{sr}: (Ref. 19, p.9)

$$f_{sr} = f_{si} - N_r[(1+C_r)\ f_{cr} - f_{ci}] =$$

$$= 185345 - 6[(1+2.0)\ 1419.1 - 1775.7] = 170{,}455 \text{ psi}$$

f) Cylinder ring stress - f_{yi}: (see Ref. 19, p.9)

Initial steel cylinder stress =

$$f_{yi} = N_i f_{ci} = 7\text{x}1775.7 = 12430 \text{ psi}$$

g) Resultant steel cylinder ring stress $-f_{yr}$: (see Ref. 19, p.9)

$$f_{yr} = f_{yi}+N_r[(1+C_r)f_{cr}-f_{ci} =$$

$$= 12430 + 6[(1+2.0)\ 1491.9-1775.7] = 27{,}319.6 \text{ psi} < f_{yb} = 45{,}000$$

(see Table IX, p. 112)

6. INTERNAL PRESSURE CRITERIA

a) Pressure at which stress in concrete and cylinder is zero (prestressing is counteracted by inside pressure) at no external load:

$$P_o = \frac{f_{cr}}{6D_y}\,[A_c+N_r(A_s+A_y)] \qquad \text{(see Ref. 19,p.10)}$$

$$= \frac{1427}{6x63}\,[52.85 + 6(0.5586+0.7176)] = 228 \text{ psi (see Fig. 20)}$$

b) Bursting pressure - P_b (see nomenclature, p.110)

$$P_b = \frac{f_{su}A_s+f_{yb}A_y}{6D_y} \qquad \text{(see Ref. 19,p.10)}$$

$$= \frac{293000x0.5586+45000x0.7176}{6x63} = 518 \text{ psi (see fig. 20)}$$

c) Elastic limit pressure $-P_L$ (see nomenclature, p.110)

$$1.70\ P_w = 1.70x150 = 255 \text{ psi}$$

$$P_L = \frac{f_{sg}}{6D_y}\,[A_s+A_y(R_1+R_2)] \geq 1.70\ P_w$$

$$= \frac{219750}{6x63}\,[0.5586+0.7176\ (0.05+0.05)] = 366 \text{ psi} > 255 \text{ psi}$$

7. EARTH LOADING ON PIPE:

a) Trench width - B_d:

O.D. of pipe = B_c = 70.75" (see pipe data, p.140)

width of trench = B_d = B_c+24" = 70.75+24 = 94.75 in. or 7.9 ft.

b) Transition width - T.W.:

As the width of the ditch increases, other factors remaining constant, the load on a rigid conduit increases in accordance with the theory for a ditch conduit until it equals the load determined by the theory for a projecting conduit. The trench width at which this load equality develops is called the Transition Width (T.W.)

T.W. = 8'-7" (see Ref. 20, p.127)

for k_u = 0.19, r_{sd} P = 0.50, W = 120 lbs/c.f. and H = 8 ft.

where k = Rankine's ratio

M = coefficient of internal friction of the backfill material

r_{sd} = settlement ratio (see Ref. 20)

P = projection ratio (see Ref. 20)

W = soil density

Since the ditch width B_d, is less than the transition width T.W., the earth loading should be designed as a trench loading.

7c) Trench load coefficient - C_d:

$$C_d = \frac{1-e^{-2k_\mu{}'H/B_d}}{2K_\mu{}'}$$

where k = Rankine's ratio of lateral pressure

to vertical pressure = $\frac{1-\sin\phi}{1+\sin\phi}$

and μ' = coefficient of sliding friction backfill material and the trench walls

and H = height of cover over pipe = 8 ft.

$k\mu'$ = 0.110 (for saturated clay)

$$C_d = \frac{1-e^{-2x0.11x8/7.9}}{2x0.11} = 0.908$$

$W_s = \gamma_e$ = 120 lbs/cubic foot

d) Trench Load - W_e:

$W_e = C_d W B_d{}^2$ by Marston's Trench Load theory (see Ref. 20, p.25)

$W_e = 0.908x120x7.9^2$ = 6800 lbs./1.f.

By the United States Bureau of Reclamation (BuRec)

$W_s = 2R_m \; H \; W_e$ (does not govern in this example)

R_m = mean radius of pipe (in ft.)

W_s = unit weight of earth cover (lbs/c.f.) which takes into account the overburden effect

$W_s = 100+20 \frac{H}{OD} \leq 150$ max. (Ref. 19,p.19)

O.D. = outside diameter of pipe

$W_e = 2x2.724x8.0x(100+20 \frac{8.0}{5.9})$ = 5540* lbs/1.f.

*The BuRec formula may give values of W_e larger than Marston's depending on earth cover.

8. <u>Traffic Loading on Pipe W_u:</u>

$W_{LL} = C_s \frac{PF}{L}$ lbs/l.f.

P = Single wheel load for AASHO H-20 truck load = 16,000 lbs.

F = Impact factor = 1.5 for paved highway (see Ref. 35, p.207)

C_s = coefficient, function of,

$B_c/2H$ and $L/2H$

$\frac{B_c}{2H} = \frac{5.9}{2x8} = 0.37$

$C_s = 0.320$ (from Ref. 35, p.206)

$\frac{L}{2H} = \frac{16.0}{2x8} = 1.0$

(Effective distribution length of concentrated load)

L = 2xHxtg 45° = 2x8x1.00 = 16.00 ft.

The effective length of pipe is the length over which the average load due to traffic produces a stress which is the same as that caused by the actual variable intensity load. Little research information is available to accurately determine such an equivalent length and hence, a 45° distribution has been assumed here. (see Ref. 35, p.207)

9. Seismic Loading - W_{su}:

$W_{su} = P_{eq} x B_c = 2200x5.9 = 13000$ lbs/l.f.

10. Summary of Individual Loads:

1. Pipe weight W_p = 1200 lbs/Lin. ft.
2. Water Weight W_w = 1225 "
3. Earth cover W_d = 6800 "
4. Operating pressure P_w - 150 psi
5. Internal Vacuum Pres. P_{vac} = -10 psi
6. Incremental pressure due to durge = ΔP_{sp} = 60 psi
7. Traffic loading W_{LL} = 480 lbs/lin.ft.
8. Seismic loading $W_{seismic}$ = 13,000 lbs/lin.ft.

11.– PROPERTIES OF COMPOSITE PIPE:

a)

COMPOSITE SECTION WITH CONCRETE PROTECTIVE COATING

(USE AT CROWN AND INVERT FOR ALL LOADINGS EXCEPT SEISMIC)

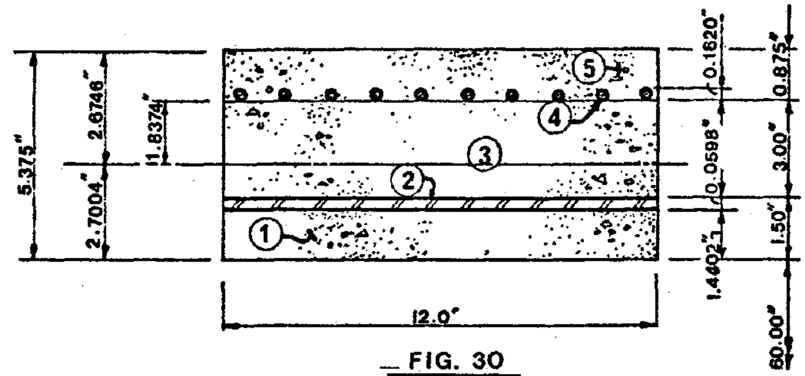


FIG. 30

	TRANSF. AREA: $A_t = bdn_r$ (in²)		Y (in)	$A_t \times Y$ (in³)	$\bar{Y}$ (in) (C−Y)	$\bar{Y}^2$ (in²)	$A_t \bar{Y}^2$ (in⁴)
1	(12×1.4402)×1 =	17.2824	0.7201	12.4451	1.9803	3.9216	67.7745
2	(12×0.0598)×6 =	4.3056	1.4701	6.3297	1.2303	1.5136	6.5171
3	(12×3.0)×1 =	36.0000	3.0000	108.0000	0.3374	0.1138	4.0982
4	0.5586×(6−1) =	2.7901	4.5810	12.7814	1.9184	3.6803	10.2683
5	(12×0.875)×1 =	10.5000	4.9375	51.8438	2.2749	5.1752	54.3393
	ΣA_t =	70.8781	$\Sigma A_t \times Y$ =	191.400	$\Sigma A_t \bar{Y}^2$ =		142.9974

the centroid is, $C = \frac{\Sigma A_t xY}{\Sigma A_t} = \frac{191.4}{70.88} = 2.7004$ in., $\quad 5.375 - C = 2.6746$ in.

$$I_o = \frac{12x1.44023}{12} + \frac{6x12x0.5983}{12} + \frac{12x3.0^3}{12} + \frac{\pi x0.162^4}{64} \quad (6-1)x\frac{12}{0.443} =$$

$$= 2.9872 + 0.0013 + 27.0000 + 0.0046 = 29.9931 \text{ in}^4$$

$$I = I_o + \Sigma A_t x\bar{Y} = 29.9931 + 142.9974 = 173.0 \text{ in}^4$$

Section Modulus, S :

Inside of pipe, $S = \frac{173.0}{2.70} = 64.1$ in^3

At face of core, $S = \frac{173.0}{2.68} = 64.8$ in^3

At extreme fiber, $S = \frac{173.0}{1.80} = 96.1$ in^3

Total Area

$A_{t_1} = \Sigma A = 70.878$ in.^{2}/l.f.

b)

COMPOSITE SECTION WITH CRACKED PROTECTIVE COATING

(USE AT SPRINGLINE FOR ALL LOADINGS EXCEPT SEISMIC)

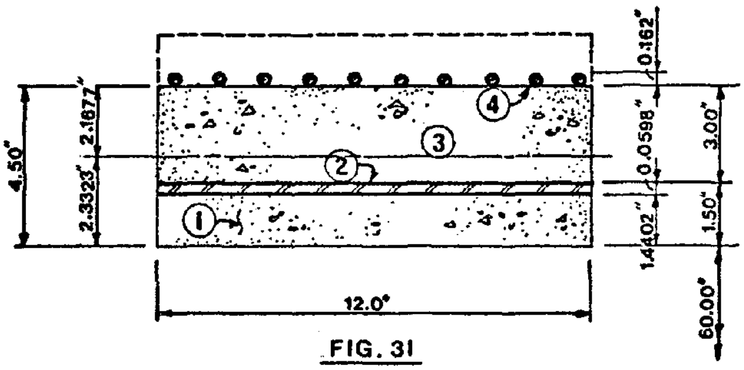


FIG. 31

TRANSF. AREA: $A_t = bdn_r$ (in²)		Y (in)	$A_t \times Y$ (in³)	$\bar{Y}$ (C−Y) (in)	$\bar{Y}^2$ (in²)	$A_t\,\bar{Y}^2$ (in⁴)
1	(12×1.4402)×1 = 17.2824	0.7201	12.4451	1.6122	2.5992	44.9202
2	(12×0.0598)×6 = 4.3056	1.4701	6.3297	0.8622	0.7434	3.2007
3	(12×3.0)×1 = 36.0000	3.0000	108.0000	0.6989	0.4884	17.5831
4	0.5586×6 = 3.3516	4.5810	15.3537	2.2799	5.1979	17.4214
	Σ A_t = 60.9396	Σ $A_t \times Y$ = 142.1285			Σ $A_t \times \bar{Y}^2$	83.1254

the centroid is, $C = \dfrac{\Sigma A_t x Y}{\Sigma A_t} = \dfrac{142.1}{60.9} = 2.3323$ in., $\quad 4.5 - C = 2.1677$ in.

$$I_o = \frac{12x1.4402^3}{12} + \frac{6x12x0.0598^3}{12} + \frac{12x3.0^3}{12} + \frac{\pi x0.162^4}{64} \; x \; 6 \; x \; \frac{12}{0.443} = 29.9940 \text{ in}^4$$

$$I = I_o + \Sigma A_t x\bar{Y}^2 = 29.9940 + 83.1255 = 113.1195 \quad \text{in}^4$$

Section Modulus, S :

At face of core, $S = \dfrac{113.1}{2.33} = 48.5 \text{ in}^3$

Inside of pipe, $S = \dfrac{113.1}{2.17} = 52.1 \text{ in}^3$

Total Area

$A_{t_2} = 60.940 \text{ in.}^2/\text{l.f.}$

WORKING STRESS DESIGN METHOD:

a) Loading Conditions

L.C. (1) - Earth Load + Pipe Load + Vacuum Pressure

L.C. (2) - Earth Load + Pipe Load + Water Load + Design Pressure

L.C. (3) - L.C. 2 + Incremental Pressure Due to Surge

L.C. (4) - L.C. 2 + Traffic Loading

L.C. (5) - L.C. 2 + Traffic Loading + Seismic Loading

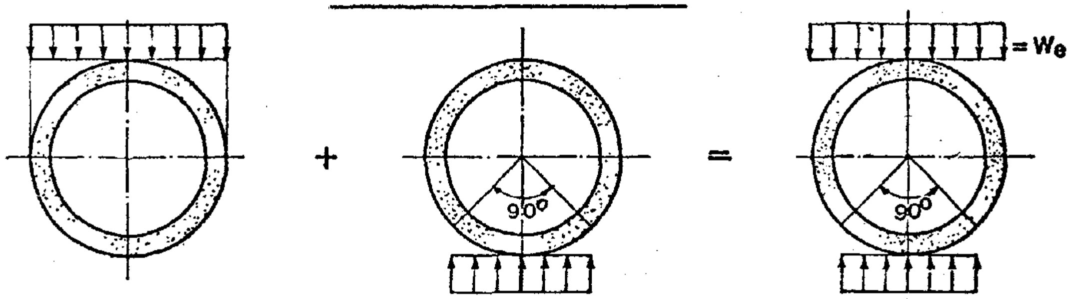
L.C. (6) - L.C. 1 + Traffic Loading

L.C. (7) - L.C. 1 + Traffic Loading + Seismic Loading

L.C. denotes Loading Condition

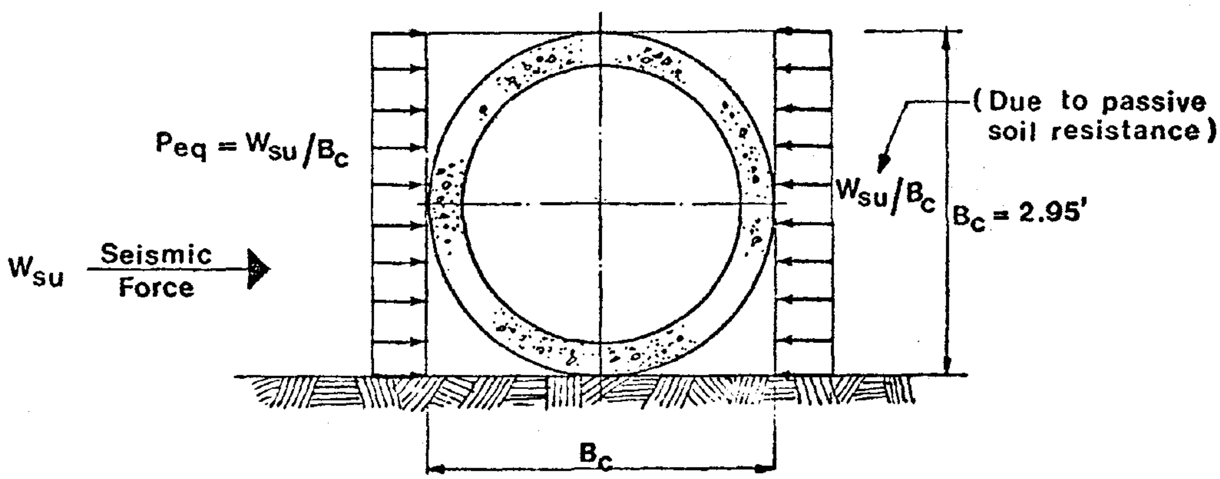
b) RING MODELS AND MEAN RADII

BEDDING ANGLE – 90°



PIPE RING MODEL FOR EARTH AND TRAFFIC LOADINGS

Fig. 32 A



PIPE RING MODEL FOR SEISMIC FORCE

Fig. 32 B

MEAN RADIUS OF PIPE = R

At Invert & Crown $R = (D+t_w)/24$ (ft.) 751-

At Springline $R = (D+t_c)/24$ (ft.)

12 c)

GENERAL FORMULAS FOR THRUST AND MOMENT		
LOADING COMPONENTS	THRUST (lbs./ft.)	MOMENT (ft.-lbs./ft.)
PIPE WEIGHT	$F_p = C_2 W_p$	$M_p = C_4 W_p R$
WATER WEIGHT	$F_w = C_5 W_w$	$M_w = C_6 W_w R$
EARTH COVER	$F_e = C_1 W_e$	$M_e = C_2 W_e R$
INTERNAL PRESSURE-HOOP FORCE	$F_h = C_9 P$	———
SEISMIC LOADING	$F_{su} = C_7 W_{su}$	$M_{su} = C_8 W_{su} R$

TABLE XXII

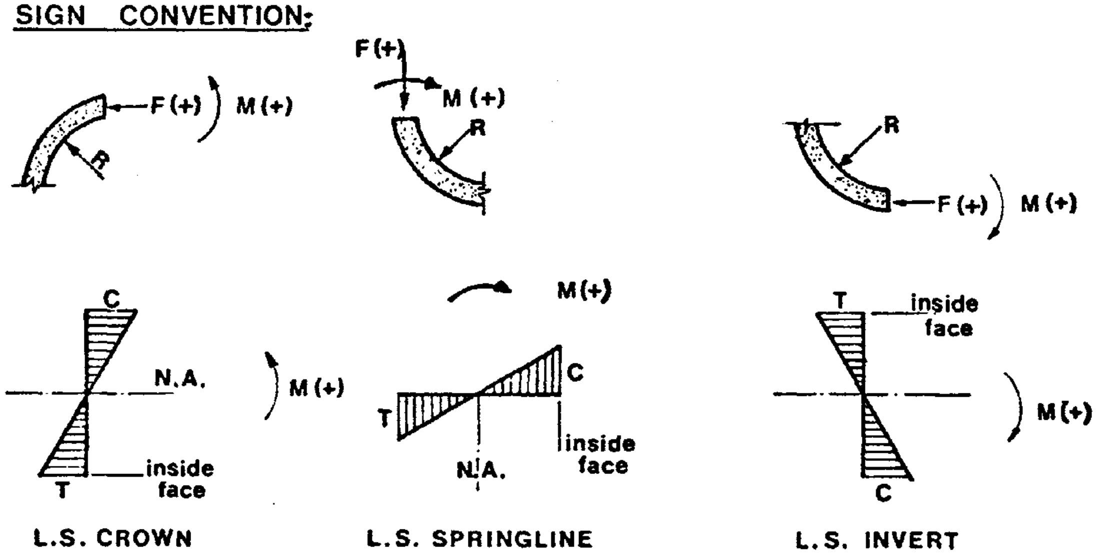
12 d)

FORCE AND MOMENT COEFFICIENTS				
LOADING	SPRINGLINE		INVERT	
	THRUST	MOMENTS	THRUST	MOMENTS
PIPE WEIGHT	$C_1 = 0.25$	$C_3 = 0.077$	$C_1 = 0.053$	$C_3 = 0.102$
WATER WEIGHT	$C_2 = 0.068$	$C_4 = 0.077$	$C_2 = 0.408$	$C_4 = 0.102$
EARTH COVER	$C_5 = 0.500$	$C_6 = 0.140$	$C_5 = 0.027$	$C_6 = 0.157$
INTERNAL PRESSURE *	$C_9 = 378.$	———	$C_9 = 378.$	———
SEISMIC	$C_7 = 0.$	$C_8 = 0.125$	$C_7 = 0.500$	$C_8 = 0.125$

* Internal pressure may be a working pressure, incremental pressure due to surge, or a vacuum pressure (negative).

TABLE XXIII

12 e) SIGN CONVENTION:



SIGN CONVENTION FOR FORCES AND STRESSES

L.S.-Denotes left side.
(+) -Denotes compression.
(−) -Denotes tension.

12d) Force and Moment Coefficients:

Two kinds of force coefficients are generally used by industry in determining the thrusts and moments for points on the pipe. The first of these are coefficients for large horizontal pipes developed by J.M. Paris in 1921 (see Ref. 45, p.768). The second are coefficients arrived at by H.C. Olander in 195 (see Ref. 18, p.10 and Ref. 19, p.15). For a discussion of methodologies in determining these coefficients, and an explanation of the differences in the values of thrust and moment obtained from each, see Section IV 3C.

In Table XII following, C_1 to C_8 are the force coefficients for circular pipes by Paris, and C_9 is the force coefficient for the hoop force in the ring = $12D_y/2 = 6D_y$.

12f)

THRUSTS AND MOMENTS DUE TO LOADING COMPONENTS					
LOADING COMPONENTS (bedding angle 90°)		INVERT		SPRINGLINE	
		THRUST (lb./ft.)	MOMENT (ft.-lbs./ft.)	THRUST (lb./ft.)	MOMENT (ft.-lbs./ft.)
A	PIPE WEIGHT	64	333.42	300	248.33
B	WATER WEIGHT	-500	340.42	-83	252.50
C	EARTH COVER	184	2908.33	3400	2558.50
D	INTERNAL PRESSURE-HOOP FORCE	-56700	—	-56700	—
E	VACUUM PRESSURE	3780	—	3780	—
F	INCREMENTAL PRESSURE DUE TO SURGE	-22680	—	-22680	—
G	TRAFFIC LOADING	13	205.33	240	180.58
H	SEISMIC LOADING *	6500	4367.17	—	4426.75

12g)

STRESSES DUE TO LOADING COMPONENTS - Δf_{crl} (psi)							
LOADING COMPONENTS		INVERT			SPRINGLINE		
		THRUST-F/A	MOMENT-M/S		THRUST-F/A	MOMENT-M/S	
			I.F.	O.F.		I.F.	O.F.
A	PIPE WEIGHT	1	-61	42	5	61	-58
B	WATER WEIGHT	-7	-63	43	-1	62	-59
C	EARTH COVER	3	-536	370	54	627	-598
D	INTERNAL PRESSURE-HOOP STRESS	-777	—	—	-899	—	—
E	VACUUM PRESSURE	52	—	—	60	—	—
F	INCREMENTAL PRESSURE DUE TO SURGE	-311	—	—	-359	—	—
G	TRAFFIC LOADING	—	-38	26	4	44	-42
H	SEISMIC LOADING *	103	1070	-1022	—	-816	563

Notes:

* For seismic loading the invert is considered cracked, and the springline uncracked.

SIGN CONVENTION:

Minus sign (-) denotes tension.
No sign (positive value) denotes compression.

I.F. - Inner face of pipe.
O.F. - Outer face of pipe.

12h) Summations for Critical Stresses from Loading Conditions

For each of the loading conditions outlined in the flowchart for the final design of water pipe line, (Fig. 19), there is a resultant internal core stress change due to the internal and external loads. Therefore, for any loading condition the resultant core stress change Δf_{cr} due to the corresponding loading components equals the summation of the Δf_{cr} due to each loading component.

The resultant core stress changes Δf_{cr} combined with the precompression core stress f_{cr} (due to prestressing) gives the net core resultant stress, f_{ncr} = for each loading condition. The f_{ncr}'s must be compared with the allowable working stresses defined by the stress analysis design method of AWWA Standard C301, (see Part III subdivision 16).

In order to obtain a summation for the Δf_{cr}'s, add all the values for the loading components and combination of loading conditions from left to right in any row of Tables XXVI to XXXII. The values for the f_{cr}'s are shown in the second column from the extreme right of the table. The final right-hand column shows the final net core stresses - f_{crn}'s for points on the pipe for a given loading condition, when the precompression core stress f_{cr} due to prestressing is added to these summations.

12h)

SUMMATION OF STRESSES – LOADING CONDITION 1									
STRESS LOCATION / LOADING		A – PIPE WEIGHT STRESSES (psi)		C – EARTH COVER STRESSES (psi)		E – VACUM PRESSURE STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST	MOMENT	THRUST	MOMENT	THRUST	MOMENT		
SPRINGLINE	I. F.	5	61	56	633	62	—	817	2236
	O. F.	5	– 57	56	– 589	62	—	– 523	896
INVERT	I. F.	1	– 62	3	– 544	53	—	– 549	870
	O. F.	1	42	3	363	53	—	462	1881

TABLE XXVI

SUMMATION OF STRESSES – LOADING CONDITION 2											
STRESS LOCATION / LOADING		A – PIPE WEIGHT STRESSES (psi)		B – WATER WEIGHT STRESSES (psi)		C – EARTH COVER STRESSES (psi)		D – INTERNAL PRESSURE-HOOP STRESS (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST	MOMENT	THRUST	MOMENT	THRUST	MOMENT	THRUST	MOMENT		
SPRINGLINE	I. F.	5	61	– 1	62	56	633	– 930	—	114	1305
	O. F.	5	– 57	– 1	– 58	56	– 589	– 930	—	– 1574	– 155
INVERT	I. F.	1	– 62	– 7	– 63	3	– 544	– 800	—	– 1472	– 53
	O. F.	1	42	– 7	43	3	363	– 800	—	– 355	1064

TABLE XXVII

SUMMATION OF STRESSES – LOADING CONDITION 3						
STRESS LOCATION / LOADING		L.C. (2) STRESSES (psi)	D – INCREMENTAL HOOP STRESS DUE TO SURGE (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST + MOMENT	THRUST	MOMENT		
SPRINGLINE	I. F.	– 114	– 372	—	– 486	933
	O. F.	– 1574	– 372	—	– 1946	– 527
INVERT	I. F.	– 1472	– 320	—	– 1792	– 373
	O. F.	– 355	– 320	—	– 675	744

TABLE XXVIII

12h)

SUMMATION OF STRESSES – LOADING CONDITION 4						
STRESS LOCATION / LOADING		L.C. (2) STRESSES (psi)	G – TRAFFIC STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST + MOMENT	THRUST	MOMENT		
SPRINGLINE	I. F.	– 114	4	45	– 65	1354
	O. F.	– 1574	4	– 42	– 1612	– 193
INVERT	I. F.	– 1472	0	– 38	– 1510	– 91
	O. F.	– 355	0	26	– 329	1090

TABLE XXIX

SUMMATION OF STRESSES – LOADING CONDITION 5								
STRESS LOCATION / LOADING		L.C. (2) STRESSES (psi)	G - TRAFFIC STRESSES (psi)		H - SEISMIC STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST + MOMENT	THRUST	MOMENT	THRUST	MOMENT		
SPRINGLINE	I. F.	– 114	4	45	0	– 829	– 894	525
	O. F.	– 1574	4	– 42	0	553	– 1059	360
INVERT	I. F.	– 1472	0	– 38	107	1081	– 322	1097
	O. F.	– 355	0	26	107	– 1006	– 1228	191

TABLE XXX

SUMMATION OF STRESSES – LOADING CONDITION 6						
STRESS LOCATION / LOADING		L.C. (1) STRESSES (psi)	G – TRAFFIC STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST + MOMENT	THRUST	MOMENT		
SPRINGLINE	I. F.	817	4	45	866	2285
	O. F.	– 523	4	– 42	– 561	858
INVERT	I. F.	– 549	0	– 38	– 587	832
	O. F.	462	0	26	488	1907

TABLE XXXI

12h)

SUMMATION OF STRESSES - LOADING CONDITION 7								
STRESS LOCATION \ LOADING		L.C. (1) STRESSES (psi)	G - TRAFFIC STRESSES (psi)		H - SEISMIC STRESSES (psi)		Δf_{cr} (psi)	$f_{ncr} = f_{cr} + \Delta f_{cr}$ (psi)
POSITION	FACE	THRUST + MOMENT	THRUST	MOMENT	THRUST	MOMENT		
SPRINGLINE	I.F.	817	4	45	0	-829	37	1456
	O.F.	-523	4	-42	0	553	- 8	1411
INVERT	I.F.	-549	0	-38	107	1081	601	2020
	O.F.	462	0	26	107	-1006	-411	1008

TABLE XXXII

Conclusion:

Pipe is adequate. All stresses are below allowable values.

Critical loading conditions are:

Steady State Loading:

Loading (1) Springline I.F.: 2236 psi < 2250 psi allow. (see p.142)

Loading (2) Springline O.F.: -155 psi < 530 psi allow.

Transient Loadings:

Loading (6) Springline I.F.: 2285 psi < 3000 psi allow. (see p. 142)

Loading (3) Springline O.F.: -527 psi < 743 psi allow.

12i) Maximum Operating Pressure and Earth Cover:

Resultant concrete stress:

$$f_c = f_{cr} - \frac{12PR_y}{A_t} \pm \frac{\Sigma F}{A_t} \pm \frac{\Sigma M}{S}$$

For tension control: $f_c \leq K \; f'_c$ $\quad K = 7.5$ (steady state)

$K = 10.5$ (transient)

a) $$P_{w\,max.} = \left[f_{cr} + K\sqrt{f'_c} + \frac{\Sigma F}{A_t} - \frac{\Sigma M}{S} \right] \frac{A_t}{12R_y}$$ (see Part III, Subdivision 16)

where the summation of the thrusts = $\Sigma F = \Sigma C \times W$

and the summation of the moments = $\Sigma M = \Sigma C x W x R_m$

C = Moment and thrust coefficients, see Tables XXII and XXIII

b) the maximum cover load, W_{dt} for tension:

$$W_{dt} = \frac{A_t S(K \; f'_c + f_{cr}) + S(\Sigma F - F_{earth}) - [A_t(\Sigma M - M_{earth}) + S(12R_y)P_w]}{C_6 R_m A_t - C_5 S}$$

(see Ref. 19, p.10)

c) for compression control: $f_c \leq K'f'_c$ $\quad K' = 0.45$ (steady state)

$K' = 0.60$ (transient)

$$f'_c = \frac{A_t S f_{cr} + S(\Sigma F) + A_t(\Sigma M) - S(12R_y)P_w}{K'A_t S}$$

solving for maximum cover load

$$W_{dc} = \frac{A_t SK' + S(12R_y)\; P_w - [A_t S f_{cr} + S(\Sigma F - F_d) + A_t(\Sigma M - M_d)}{C_6 R_m A_t + C_5 S}$$

(see Ref. 19, p.10)

12i) Tension Control

For Loading condition (3), see section 12a, p.151

Critical Location:

O.F. springline

f_{cr} = 1419 psi

K = 10.5 (for transient loading)

f'_c = 5000 psi

$\Sigma F = F_{pipe} + F_{water} + F_{earth} = 300 - 83 + 3400 = 3617$ lbs/foot

$A_t = 60.9$

$\Sigma M = M_{pipe} + M_{water} + M_{earth} = 2980 + 3042 + 30702 = 36724$ ft.lbs/foot

$S = 52.1 \text{ in}^3$

$A_t = 63.1 \text{ in}^2$

$12R_y = 378, \quad R_m = 32.25$ in.

$C_5 = 0.500, \quad C_6 = 0.140, \quad B_d = 7.9$ ft, $\quad k\mu' = 0.11$

a) $P_{s\,max.} = \left[1419 + 10.5\sqrt{5000} + \frac{3617}{60.9} - \frac{36724}{52.1}\right]\frac{60.9}{378} = 244$ psi (allowable) for surge

For P_w = 150 psi

$P_s = \left(P_w + \Delta P_{sp}\right) \leq 1.4\, P_w = 210$ psi, $P_{w\ max.} = \frac{244}{1.4} = 175$ psi $> P_w$ (allowable)

b) $$W_{dc\ max} = \frac{60.9x52.1\ (10.5\sqrt{5000} + 1419) + 52.1 \times 217 - [60.9x6022+52.1x378x210)}{0.140x32.25x60.9 - 0.500x52.1}$$

= 9509 lbs/lin.foot

$W_d = C_d \times \gamma_e \times B_d^2 \qquad C_d = \frac{9058}{120x7.9^2} = 1.21, \quad k\mu' = 0.11$

$C_d = \frac{1-e^{-2k\mu'H/B_d}}{2k\mu'} \qquad H_{max} = \frac{\ln(1-C_d 2k\mu')xB_d}{-2k\mu'}$, where ln = natural logarithm

$$= \frac{\ln(1-1.21x2x0.11) \times 7.9}{-2x0.11} = 11.1 \text{ foot}$$

12i) Compression Control:

Loading condition (1)

Steady state loading

Critical Location: I.F. Springline

$A_t = 60.9 \text{ in}^2$

$S = 48.5 \text{ in}^3$

$f_{cr} = 1419$ psi

$\Sigma F = F_{pipe} + F_{vac.} + F_{earth} = 300 + 3780 + 3400 = 7480$ lbs.

$\Sigma M = M_{pipe} + M_{vac.} + M_{earth} = 2980 + 0 + 30702 = 33682$ ft. lbs/foot

$12R_y = 378$

$P_w = -10$ psi (vacuum)

$k' = 0.45$

$R_m = 32.25$ in

$C_5 = 0.500$ $\quad R_m = 32.25$ in $\quad k\mu' = 0.11$

$C_6 = 0.140$ $\quad B_d = 7.9$ ft.

c) $$f_c'{}_{req'd} = \frac{60.9x48.5x1419+49.0x7480+60.9x33682-48.5x378x10}{0.45x60.9x48.5} =$$

$$= 4834 \text{ psi}$$

d) $$W_{d\ max.} = \frac{60.9x48.5x0.45x5000+48.5x378x10-[60.9x48.5x1419 \pm 49.x4080+60.9x2980]}{0.140x32.25x60.9+ 0.500x49.0}$$

$$= 7541 \text{ lbs/lin.foot}$$

$$C_d = \frac{7541}{120x7.92} = 1.01$$

$$H_{max.} = \frac{\ln(1-1.01x2x0.11)x7.9}{-2x0.11} = 9.0 \text{ foot}$$

13. CRACKING CONTROL CALCULATIONS

a) Bedding classes and load factors L_f:

Bedding class B - $L_f = 1.9$

Bedding Class D - $L_f = 1.1$

b) Allowable three-edge bearing load at P_w:

For cubic parabola design method

See Part III Appendix "B" Subdivision 15

Three-edge bearing load - W:

$f_{cr} = 1419$ psi,

Maximum three-edge bearing load for 0.001 crack at P = 0

$W_{.001} = 11400$ lbs/lin. foot (see Fig. 33)

$W_o = 0.9xW_{.001} = 0.9x11400 = 10260$ lbs/lin. foot

$P_o = 229$ psi (see B-4)

$P_w = 150$ psi $<P_o$

$P_s = P_w + \Delta P_{sp} = 210$ psi $< 1.4\ P_o$

For $P_w = 150$ psi W = 0.7x10260 = 7191 lbs/lin. foot (see Fig. 34) (Governs)

For $P_s = 210$ psi, W = 0.841 x 10260=`8630 lbs/lin. foot (see Fig. 34)

13c) Equivalent three-edge-bearing loads - W:

For Class "B" Bedding:

$W = W_e/L_f$ = 6800/1.9 3579 lbs/l.f. < 7191 lbs/l.f. (allowable, see Fig. 34)

For Class "D" Bedding:

$W = W_e/L_f$ = 6800/1.1 = 6182 lbs/l.f. < 7191 lbs/l.f.

PART IV. 5

PLOT OF CUBIC PARABOLA INTERACTION

FORMULA OF AWWA C 301 $W = W_O \sqrt[3]{\frac{P_O - P}{P_O}}$
FOR COMBINED STRESSES
FROM 3-EDGE BEARING AND INTERNAL PRESSURE
FOR PRESTRESSED CONCRETE CYLINDER PIPE – PCC
AND PRESTRESSED CONCRETE EMBEDDED CYLINDER – PCEC

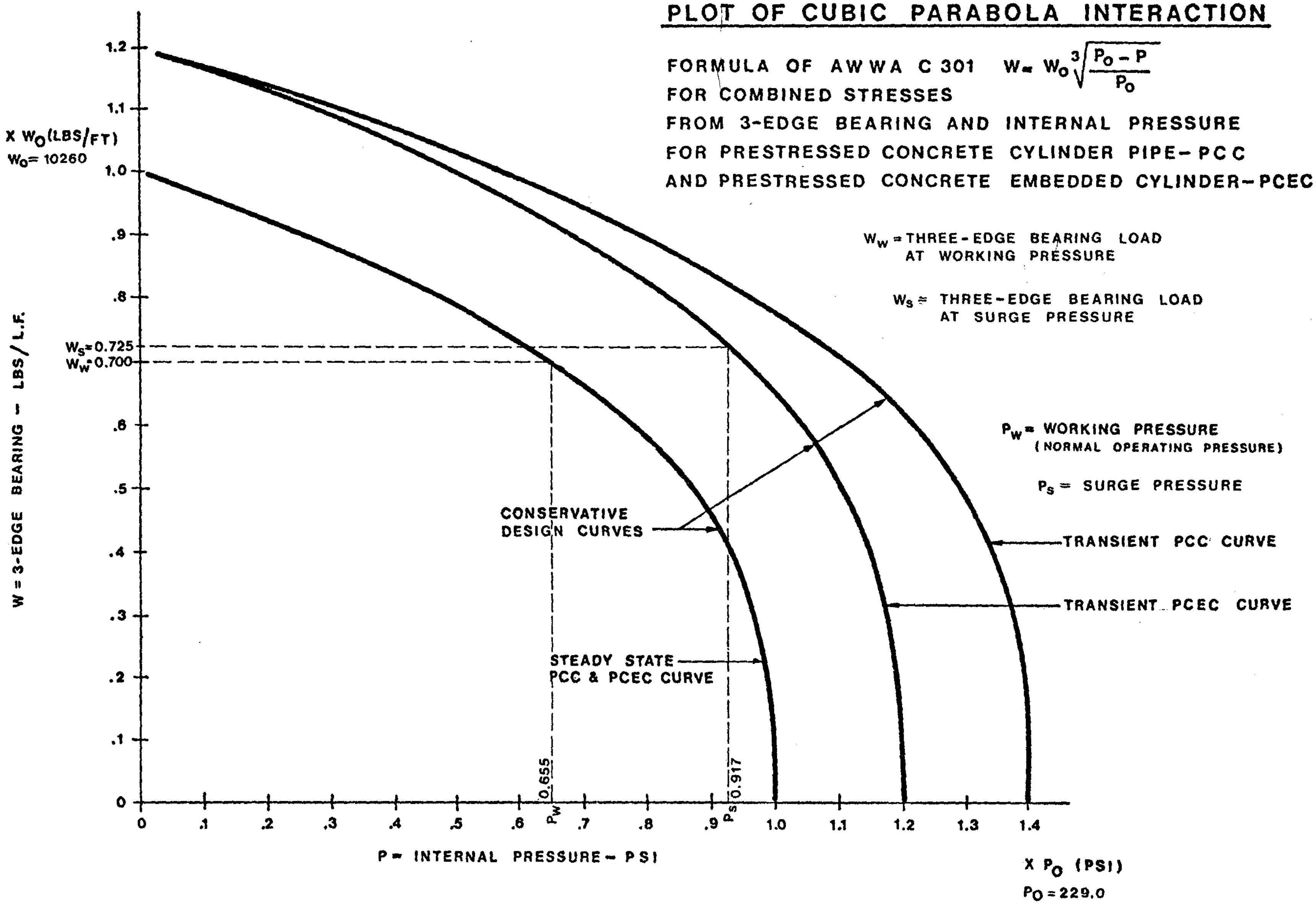


FIG. 34

PART IV 6

THREE-EDGE BEARING LOAD vs. RESULTANT CONC. CORE STRESS

PRESTRESSED CONCRETE CYLINDER PIPES – STANDARD CORES

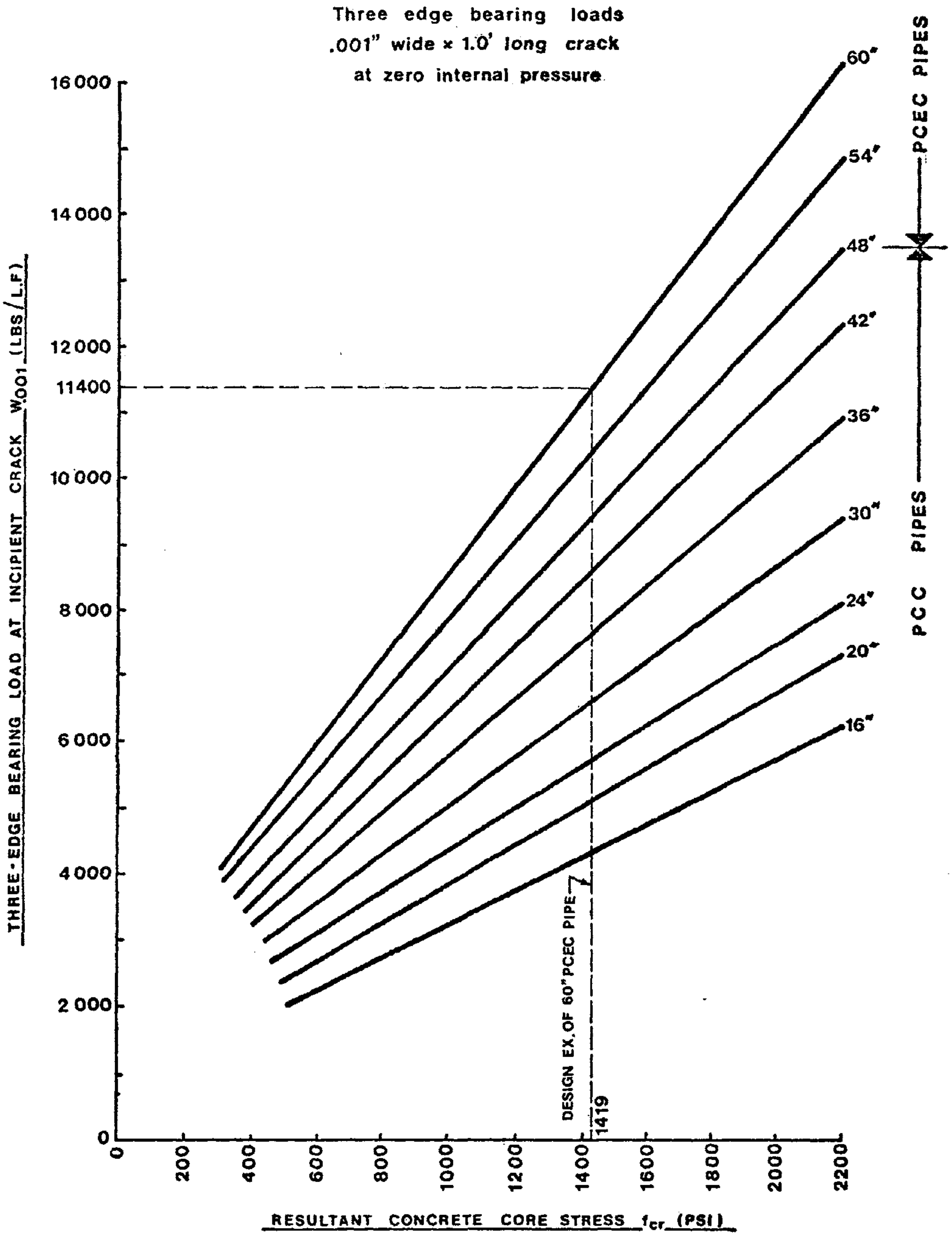


FIG. 33

PART IV. 6

PLOT OF CUBIC PARABOLA INTERACTION

FORMULA OF AWWA C 301 $W = W_O \sqrt[3]{\frac{P_O - P}{P_O}}$
FOR COMBINED STRESSES
FROM 3-EDGE BEARING AND INTERNAL PRESSURE
FOR PRESTRESSED CONCRETE CYLINDER PIPE–PCC
AND PRESTRESSED CONCRETE EMBEDDED CYLINDER–PCEC

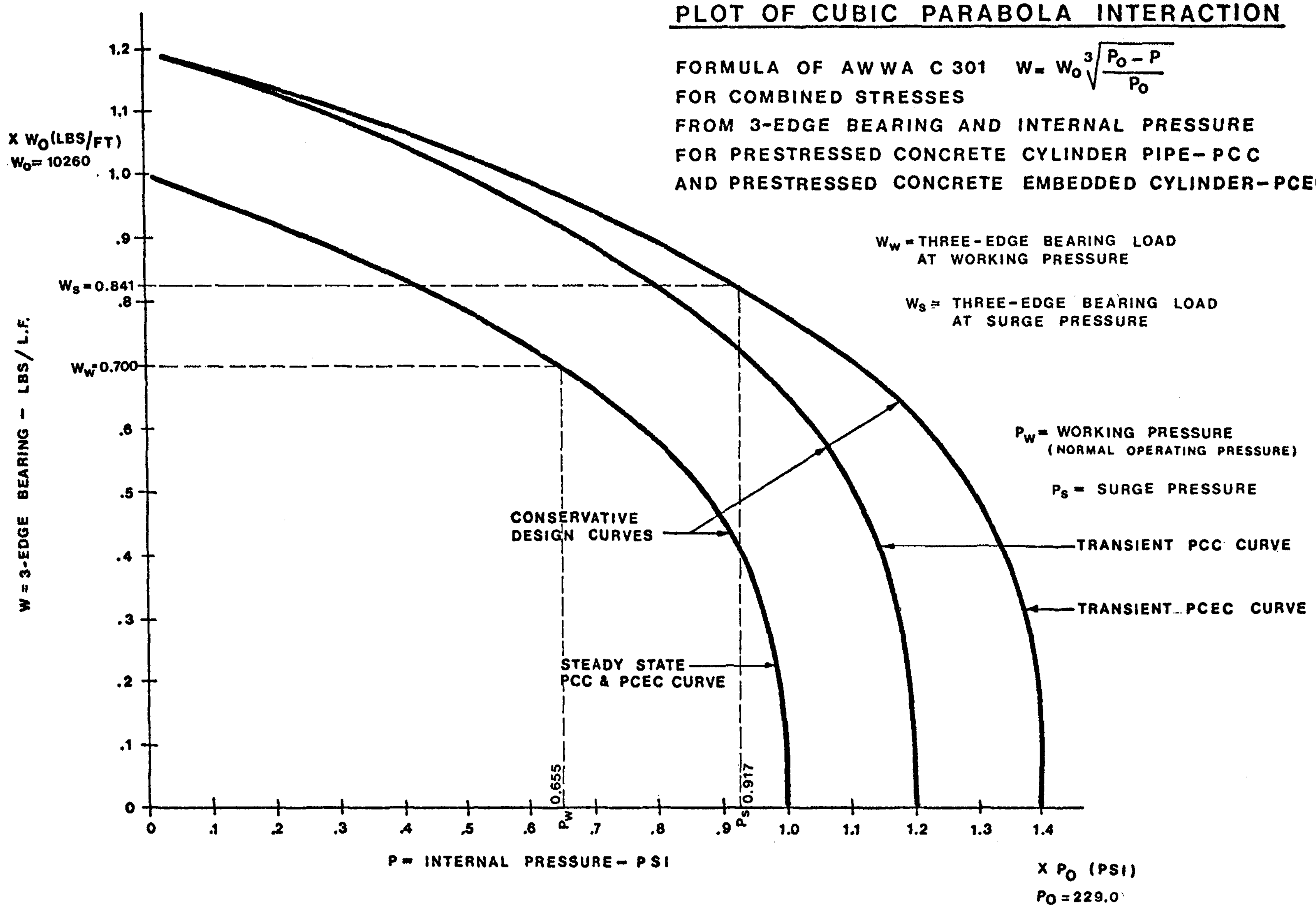


FIG. 34

PART V

STATIC AND DYNAMIC PIPE AND JOINT BEHAVIOR

1. Ultimate Interaction Curves

a) Ultimate Interaction Curves for Cracking

The design examples of Part IV, for a 30" PCC pipe and a 60" PCEC pipe, are based on typical design procedures employed by industry to arrive at a pipe design based on the AWAA standards for allowable cracking and maximum stresses (see Part IV, section 5B - Crack Control-Serviceability Criteria, page 107 and section 5C - Working Stress Criteria, page 107)

In order to determine what factor of safety and reserve strength for superimposed vertical loads are inherent in typical industrial designs W.A. has reviewed the ultimate cracking loads for standard cores PCC and PCEC pipes from a compilation of information contained in technical Journals and from empirical data from industry(*), and has established a lower bound for the failure interaction curve between the equivalent three-edge-bearing load and the internal pressure. (The actual failure interaction curve can be slightly higher depending on the pipe manufacturer and the quality control achieved.)

PCC and PCEC (rigid) pipes of reinforced concrete have a factor of safety for vertical superimposed loads at a given operating pressure defined as the ratio of their ultimate three-edge-bearing load (ring compression) to that of the equivalent actual load (the field load reduced to account for the cushioning effect of the bedding). The values of the safety factor lie in the range of 3.5 to 6.0. The actual factor of safety of a

(*) W.A. wishes to thank the design staff of Interpace Corp. for their assistance in correlating the empirical data from their laboratory tests.

pressurized rigid pipe for vertical superimposed loads is well above 2.5, as the actual equivalent load must always be lower than the allowable three-edge-bearing load determined by the cubic-parabola interaction curve. This is shown on Fig. 2 for a typical 30" diameter PCC pipe.

PCEC pipes with no internal pressure have an ultimate three-edge-bearing load approximately 2.5 times the design allowable load set by AWAA Standard C301. Using this load and the bursting pressure as the ultimate internal pressure, an ultimate interaction curve may be calculated by the formula:

$$w_u = W_u \sqrt[3]{\frac{P_b - P}{P_b}}$$

where w_u = ultimate equivalent three-edge-bearing load at internal pressure p

W_u = ultimate three-edge-bearing load - 2.5 x W_o (at p = 0)

W_o = incipient cracking design vertical load at zero internal pressure (see Appendix B, Part III, 15)

P_b = bursting pressure (see Fig. 20)

The load W_o is a function of the concrete core precompression stress, f_{cr}, and the diameter of the pipe. Graphs of W_o for PCC pipes of diameters from 16"-48" and PCEC pipes of daimeters from 48-60" are shown in Fig. 1. The family of empirical curves of Fig. 1 represents the lower design bounds for incipient cracking for such pipes with standard cores, and have been developed by W.A. after correlation with data from the major manufacturers and that found in published technical papers. (See Ref. 1 and Ref. 37, 39 and 40 of Part IV.) Industry has found it convenient to express the precompression stress f_{cr} as a function which contains a loss parameter β which lumps together all the loss effects. The general formulas for f_{cr} and β are given in Fig. 20 of Part IV.

PART V

THREE-EDGE BEARING LOAD vs. RESULTANT CONC. CORE STRESS

PRESTRESSED CONCRETE CYLINDER PIPES WITH STANDARD CORES

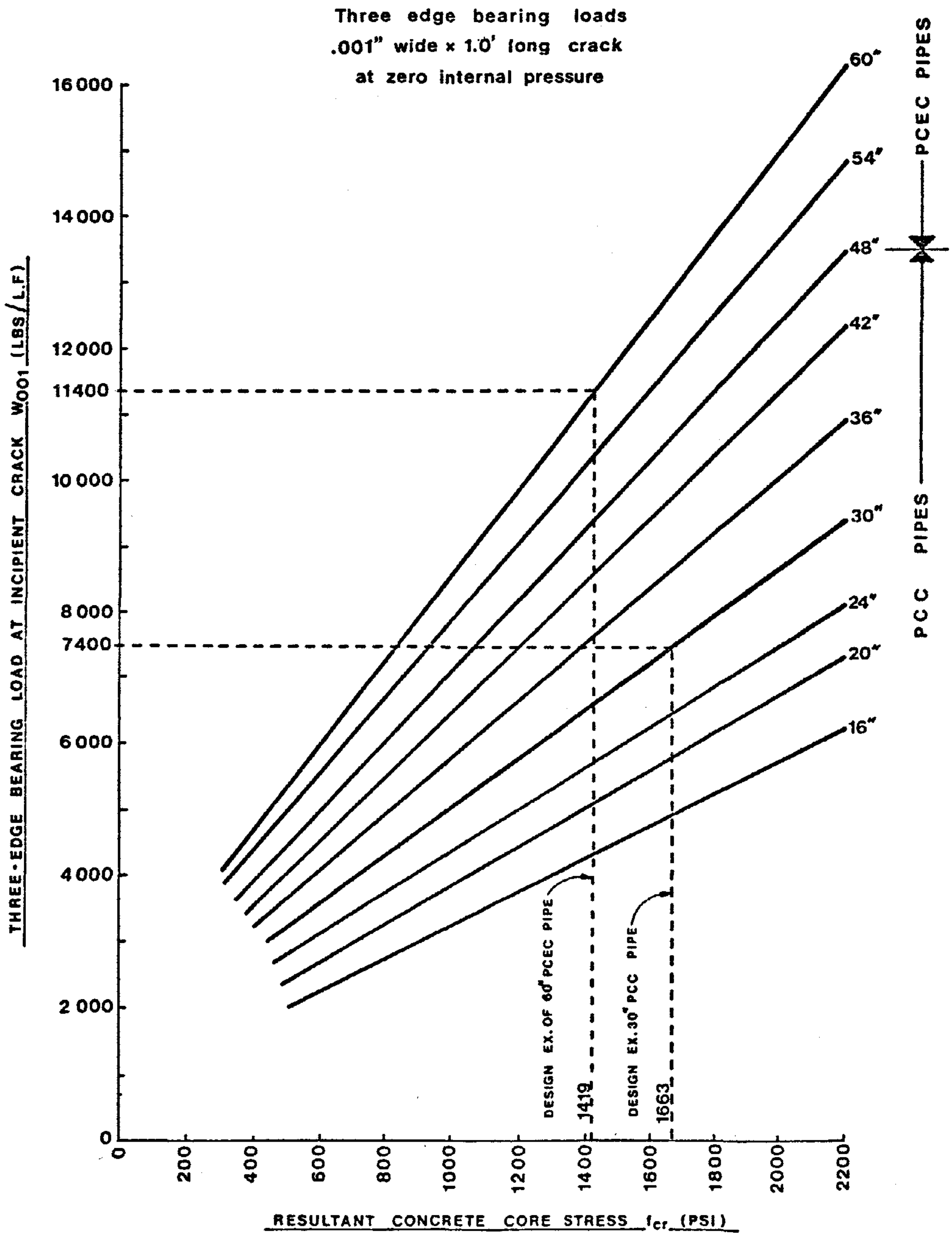


FIG. 1

A. Ultimate Interaction curve for cracking of a 30" PCC pipe:

Using the pipe input data for the 30" PCC pipe shown on page (Part IV), and the general data for prestressed pipes in Table IX and X given on pages 112-113 , Part IV, the loss parameter is given by:

$$\beta = \frac{(1 - 0.05 - 0)\left[1 + 5.0\left(\frac{0.285 + 0.7320}{21.768}\right)\right]^2}{\left[1 + 6\left(\frac{1.017}{21.768}\right)\right]\left[1 + 5.0\left(\frac{1.017}{21.768}\right)(1 + 1.50)\right]} = 0.7129$$

Using the general formula for f_{cr}, given in Fig. 20 (Part IV), the final or resultant precompression stress in the core is:

$$f_{cr} = \frac{\left(\frac{0.285}{21.768}\right)(219.750)0.7129}{1.0 + \left(\frac{5.0}{21.768}\right) 1.017} = 1663 \text{ psi},$$

and Fig. 1 gives for the three-edge-bearing load at incipient cracking the value:

$$W = 7400 \text{ lbs/l.f.}$$

Thus, the incipient cracking design load is: $W_o = 0.90\ W = 6660$ lbs/l.f., the ultimate three-edge-bearing load at no internal pressure $W_u = 2.5\ W_o$

= 16,650 lbs/l.f.

the balancing pressure $P_o = 220.48$ psi

and the bursting pressure $P_b = 560.58$ psi (see Part IV, p. 122)

With these parameters, the design cracking curve is obtained by the cubic parabola interaction formula of AWAA C301 plotted in Fig. 21, Part IV, p. 115. Non-dimensional plots of both the ultimate interaction and the design cracking curves are given on Fig. 2. With the earth load $W_e = 3146$ lbs./l.f. (see p.124 Part IV), the equivalent three-edge-bearing loads are:

for class "D" - Bedding, $W = W_e/L_f = \frac{3146}{1.1} = 2860$ lbs./l.f. $= 0.4294\ W_o$

where the load factor $L_f = 1.1$ (see Part IV.3, p.137 and Part II , Fig. 12 p.15) for class "B" Bedding, $W = W_c/L_f = \frac{3146}{1.9} = 1656$ lbs./l.f. $= 0.2486\ W_o$

where $L_f = 1.9$ (see Part II, Fig. 12, p. 15). Therefore, the factors of safety (F.S.) and the Reserve Strengths (R.S.) for Class "B" and Class "D" Beddings are:

$$\text{F.S. for Class "D" Bedding} = \frac{2.254\ W_o}{0.4294\ W_o} = 5.25$$

$$\text{F.S. for Class "B" Bedding} = \frac{2.254\ W_o}{0.2486\ W_o} = 9.07$$

$$\text{R.S. for Class "D" Bedding} = (2.254 - 0.4294)W_o = 1.83\ W_o = 12{,}152 \text{ lbs./l.f.}$$

$$\text{R.S. for Class "B" Bedding} = (2.254 - 0.2486)W_o = 2.01\ W_o = 13{,}356 \text{ lbs./l.f.}$$

These values of the F.S. and R.S. appear in Fig. 2. (Computations for the significant points of the ultimate curve have not been shown for the sake of brevity.) Values for the F.S. and R.S. of the pipe under quasistatic transient loadings, such as traffic and surge pressure, could also be similarly evaluated.

B. Ultimate Interaction Curve for Cracking of a 60" PCEC Pipe:

Using the pipe input data for the 60" PCEC pipe shown on page Part IV and the general data for prestressed pipes in Tables IX and X given on pages 112-113 , Part IV

$$\beta = \frac{(1 - 0.05 - 0.05)[1 + 6.0(\frac{0.5586 + 0.7176}{53.282})]^2}{[1 + 7.0(\frac{1.276}{53.282})][1 + 6.0(\frac{1.276}{53.282})(1 + 2.0)]}$$

$$= 0.7045$$

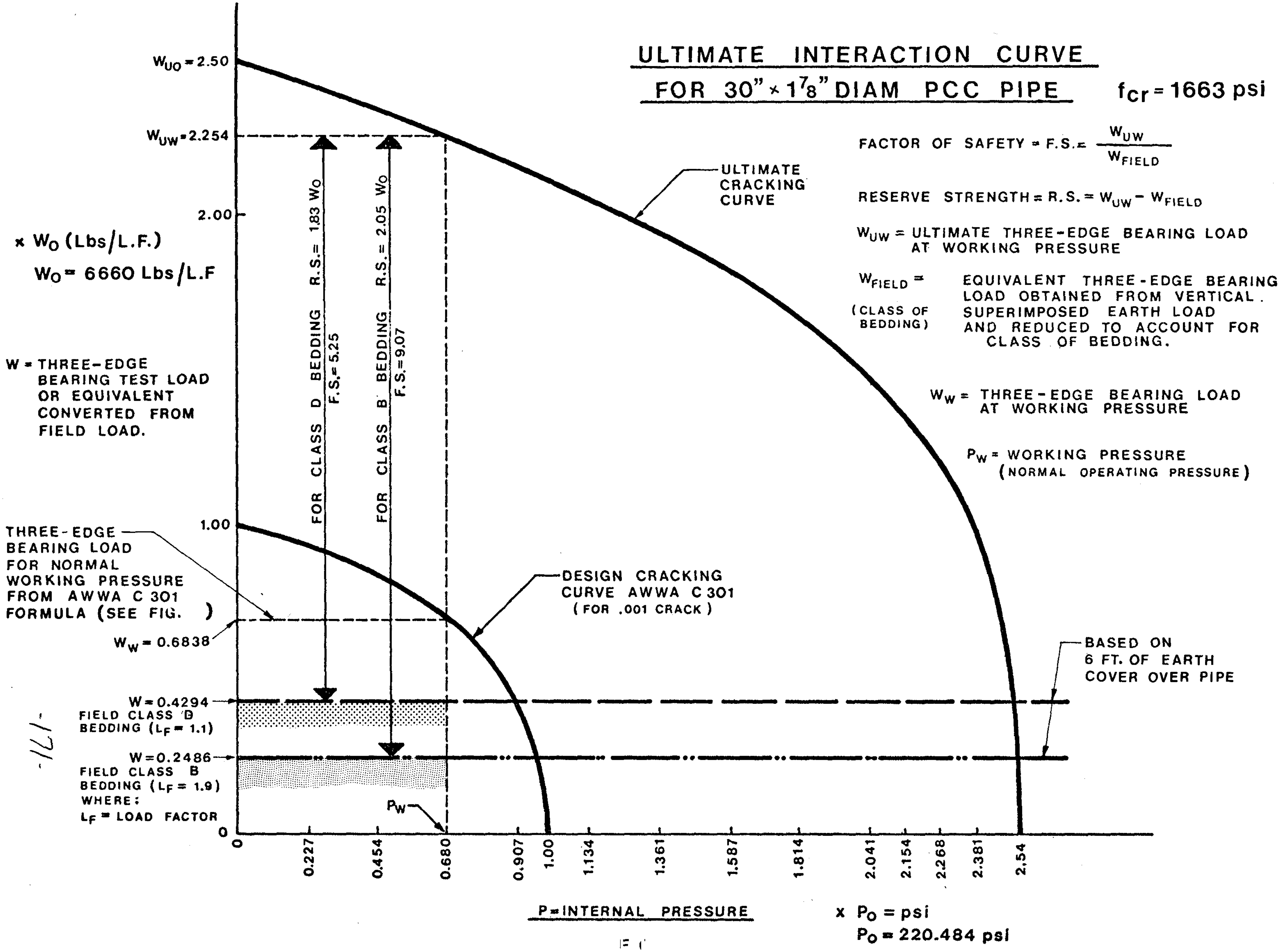
Using the general formula for f_{cr}, given in Fig. 20, Part IV, the resultant precompression stress in the core is:

$$f_{cr} = \frac{(\frac{0.5586}{53.282})(219.750)\ 0.7045}{1.0 + (\frac{6.0}{53.282})\ 1.276} = 1{,}419.1 \text{ psi}$$

ULTIMATE INTERACTION CURVE

FOR 30" × 1⅞" DIAM PCC PIPE

$f_{cr} = 1663$ psi



From Fig. 1, the three-edge-bearing load for incipient cracking

$$W = 11{,}400 \text{ lbs./l.f.}$$

The incipient cracking design load $W_o = 0.90\ W = 10{,}260$ lbs./l.f.

The ultimate three-edge-bearing load at no internal pressure $W_u = 2.5\ W_o = 25{,}650$ lbs./l.f.,

the balancing pressure $P_o = 228.78$ psi and the bursting pressure $P_b = 518.42$ psi (see Part IV, p.144).

With these parameters the design cracking curve is obtained by the cubic parabola interaction formula of AWWA C301 plotted in Fig. 21, Part IV, p. 115. Non-dimensional plots of both the ultimate interaction and the design cracking curves are given in Fig. 3. The earth load, W_e - 6,800 lbs./l.f. (see p.146, Part IV). The equivalent three-edge-bearing loads are:

for class "D" Bedding, $W = W_e/L_f = \frac{6800}{1.1} = 6182$ lbs./l.f. $= 0.6024\ W_o$

for class "B" Bedding, $W = W_e/L_f = \frac{6800}{1.9} = 3579$ lbs./l.f. $= 0.3488\ W_o$

Therefore, the factors of safety (F.S.) and the Reserve Strengths (R.S.) are:

$$\text{F.S. for Class "D" Bedding} = \frac{2.231\ W_o}{0.6024\ W_o} = 3.70$$

$$\text{F.S. for Class "B" Bedding} = \frac{2.231\ W_o}{0.3488\ W_o} = 6.40$$

R.S. for Class "D" Bedding = $(2.231 = 0.6024)W_o = 1.63\ W_o = 16{,}709$ lbs./l.f.

and

R.S. for Class "B" Bedding = $(2.231 - 0.3488)W_o = 1.88\ W_o = 19{,}311$ lbs./l.f.

These values appear in Fig. 3 .

ULTIMATE INTERACTION CURVE
FOR 60" × 4½" DIAM PCC PIPE

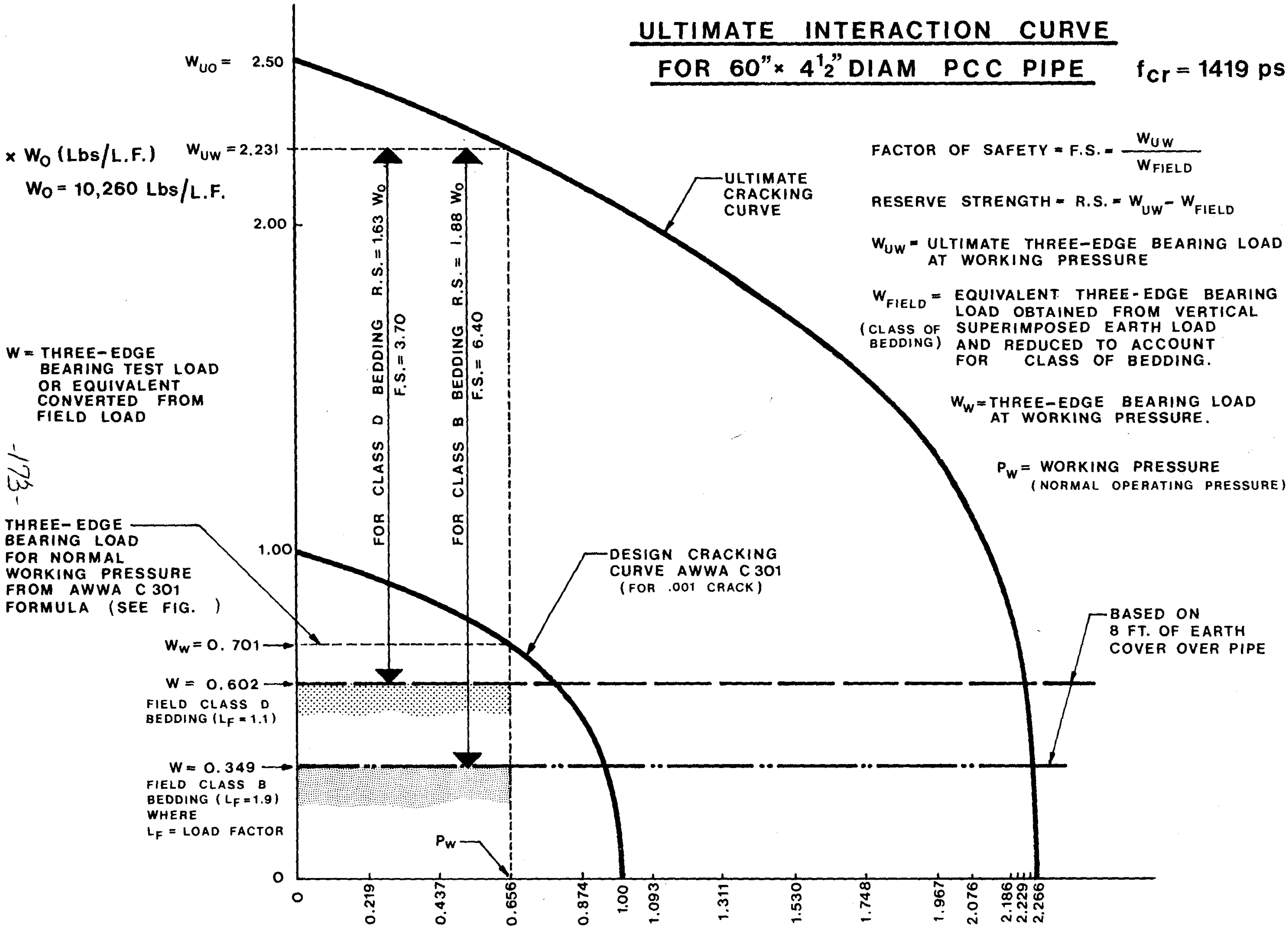


FIG. 3

b) Ultimate Interaction Curves for Stress

A) W.A. has developed an Ultimate Interaction Curve based on stress criteria for a specific pipe. In Fig. 3A, W.A. has added the ultimate-stress pressure-load interaction diagram to the allowable pressure-load interaction diagram of Fig. 7, of Ref. 19 of Part IV, in order to indicate the ultimate loads for a 54 in. PCEC pipe. Following industry's approach, the allowable and ultimate stress curves for this example have been computed using Orlando's force coefficients (see Part IV, p. 108). It should be noted that with the pressure bulb assumptions made by Orlando (see Ref. 19, Part IV) no differentiation in the class of bedding or the reaction distribution for that class are made. Therefore W.A. feels that the development of ultimate interaction curves for stress based on these assumptions are less meaningful than the ultimate interaction curves based on crack control or leakage (presented in Part V, 1a), which do take into account (although somewhat empirically) the reaction distribution for different bedding and construction conditions.

B) Calculations for Ultimate Stress Interaction Diagram

The ultimate stress calculations which follow are a supplement to the Design Example shown in pages 13-18 of Ref. 19 for a 54 in. PCEC pipe. For nomenclature and an explanation of the formulas see pages 8-10 and page 24 of Ref.19. For ultimate stress, K = 12, and K' = 1.0 have been used in the general formulas, see ACI 318-71 Sect 10.2.7 (Ref. 6, Part IV).

Tension Control:

At the invert:

Load Calculation at P = 0.

The ultimate three-edge-bearing load is:

$$W_{uo} = \frac{SA_t(12\sqrt{f'_c} + f_{cr}) + S(F_p + F_w) - A_t(M_p + M_w)}{0.126\ R_m A_t - 0.324\ S}$$

$$= \frac{(64.41(71.85)(805 + 892.4) + 64.41\ (-41) - 71.85(7613)}{(0.126)(29.75)(71.85) - (0.324)(64.41)} = 29{,}425 \text{ lbs./l.f.}$$

Pressure Calculation at W = 0

The ultimate Internal pressure is:

$$P_u = [f_{cr} + 12\sqrt{f'_c} + \frac{F_p + F_w}{A_t} - \frac{M_p + M_w}{S}]\ \frac{A_t}{6D_y}$$

$$= [892.4 + 805 + \frac{(-41)}{71.85} - \frac{7613}{64.41}]\ \frac{71.85}{6(57.5)} = 329 \text{ psi}$$

At the springline:

Load Calculation at P = 0.

The ultimate three-edge-bearing load is:

$$W_{uo} = \frac{SA_t(12\sqrt{f'_c} + f_{cr}) + S(F_p + F_w) - A_t(M_p + M_w)}{0.089\ R_m A_t - 0.539\ S}$$

$$= \frac{(49.02)(60.3)(805 + 892.4) + 49.02(266) - 60.3(5492)}{(0.089)(29.75)(60.3) - (0.539)(49.02)} = 35{,}270 \text{ lbs./l.f.}$$

Pressure Calculation at W = 0.

The ultimate internal pressure is:

$$P_u = [f_{cr} + 12\sqrt{f'_c} + \frac{F_p + F_w}{A_t} - \frac{M_p + M_w}{S}]\ \frac{A_t}{6D_y}$$

$$= [892.4 + 805 + \frac{266}{60.3} - \frac{5492}{49.01}]\ \frac{60.3}{6(57.5)} = 278 \text{ psi}$$

Compression Control:

The ultimate three-edge-bearing load is:

$$W = \frac{A_t S\ K'\ f'_c + 6\ P_w D_y\ S}{C_6 A_t R_m + C_5\ S}$$

$$- \frac{A_t S\ f_{cr} + S(F_p + F_w) + A_t(M_p + M_w)}{C_6 A_t R_m + C_5\ S}$$

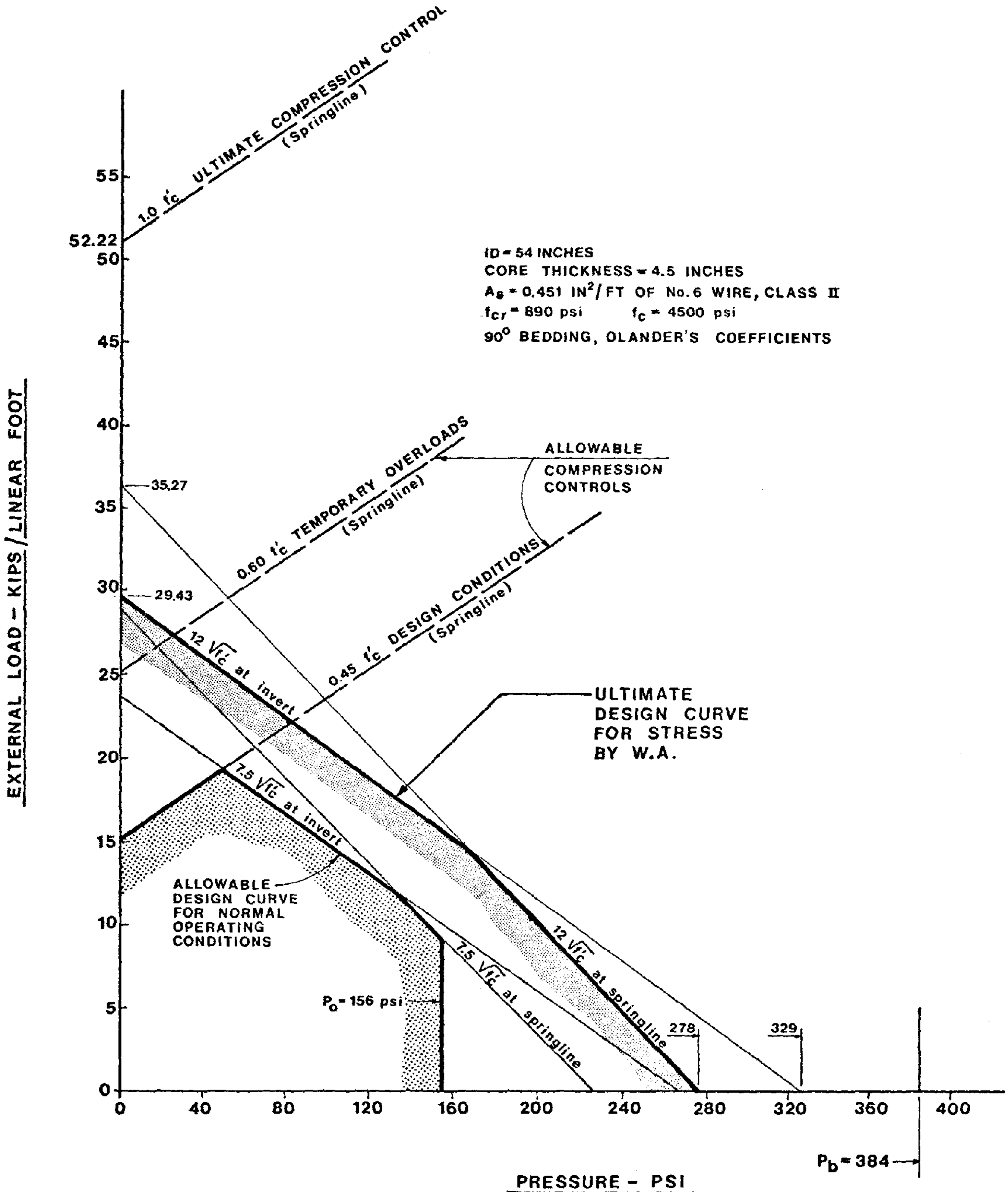
At the springline:

$$W = 14.99(4500\ K') + 85.75\ P_w - 15{,}237$$

where $K' = 1.0$ for ultimate stress.

Therefore, at $p = 0$; $W_u = 52{,}218$ lbs./l.f.

at $p = p_o = 156$ psi; $W_u = 65{,}595$ lbs./l.f.



ALLOWABLE AND ULTIMATE PRESSURE LOAD-DIAGRAM
SINGLE-LAYER WRAP-54" PCEC PIPE

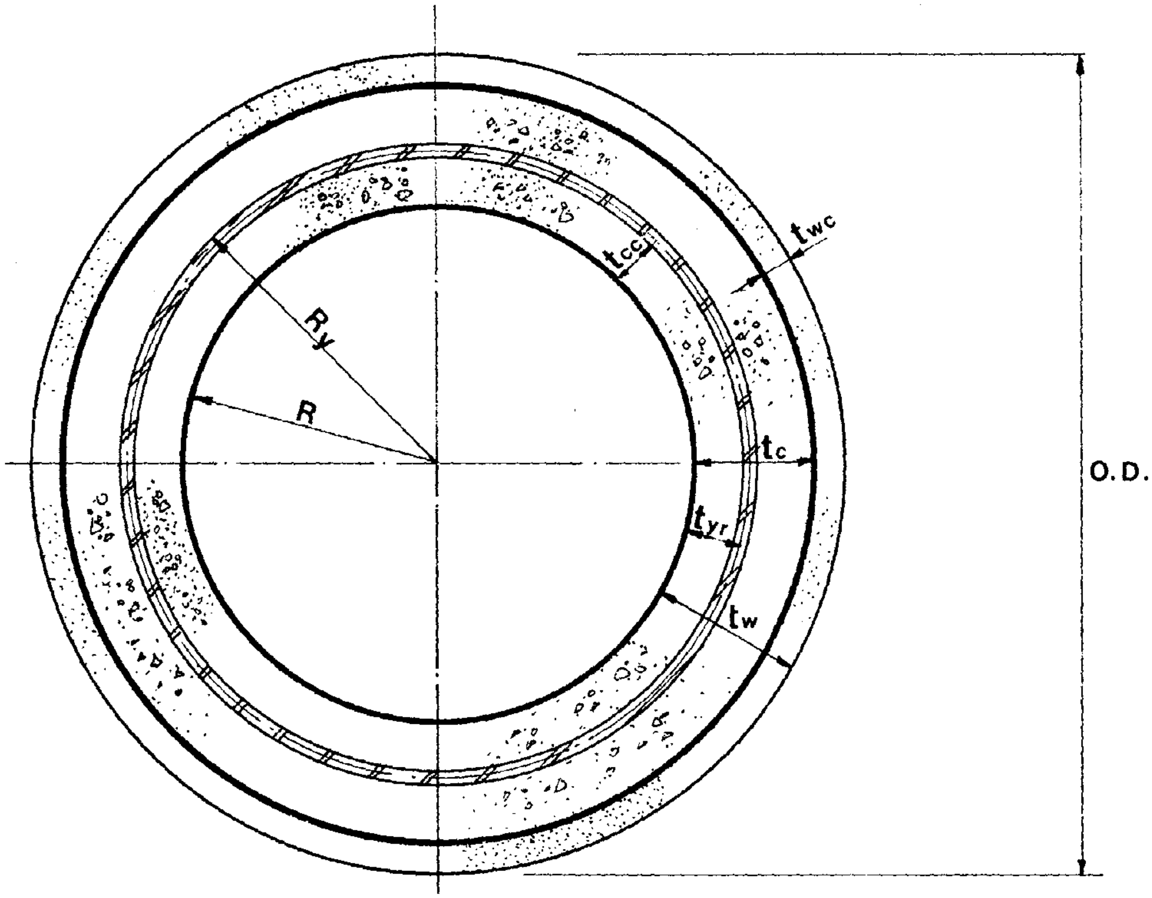
FIG. 3A

Note: Allowable Pressure Load Diagram reproduced from Fig.7 p 13 of ref.1

2. GENERAL METHODOLOGY FOR THE EVALUATION OF CHARACTERISTICS OF CONTINUOUS AND JOINTED RIGID CONCRETE PIPES

Table I (p.197) gives the elastic stiffness and the fundamental period for both extensional and transverse bending modes of a continuous isolated PCEC pipe based on an arbitrary twenty foot segment length, a length compatible with that of jointed line segments. Various degrees of cracking have been assumed in order to obtain the elastic stiffnesses enumerated in Table I and described in more detail in the calculations. It has been assumed that the materials are perfectly elastic and that there is composite action between the cylinder and the concrete without slippage. The fundamental period of vibration for an isolated continuous elastic pipe subjected to a longitudinal shear wave is a combination of its tension and compression phases shown in Table II, on page 198.

Table III, on page 199, gives the effective extensional and rotational mode stiffnesses and periods for a rubber-gasketed PCC and a PCEC pipe under a working pressure of 150 psi and for a twenty foot pipe segment. The rotational stiffness is based on the rigid body rotational motion of the pipe and water mass about the joint's crown or invert. The joint extensional and rotational characteristics have been computed as a function of the gasket compressive contact pressure and the friction developed between the gasket and the bell and spigot rings.



CROSS-SECTIONAL MODEL OF PCC & PCEC PIPES

FIG. 4

Where

t_y = Thickness of steel cylinder

t_c = Total thickness of pipe without protective covering

t_{cc} = Thickness of concrete core inside steel cylinder

t_{yr} = Radial distance from the inside of the core to the center of the steel cylinder

For PCC pipes; $t_{yr} = t_c - t_y/2$

For PCEC pipes; $t_{yr} = t_{cc} + t_y/2$

D_y = Outside diameter of steel cylinder

$R_y = D_y/2$

D = Inside diameter of core; R = D/2

t_{wc} = Thickness of outer protective mortar covering on wrapping wire

t_w = Total thickness of pipe wall with protective covering

O.D. = Outside diameter or pipe with protective covering = $D + 2t_w$

A_y = Circumferential area of steel cylinder per foot = $12t_y$

The mean radius to the composite pipe wall is:

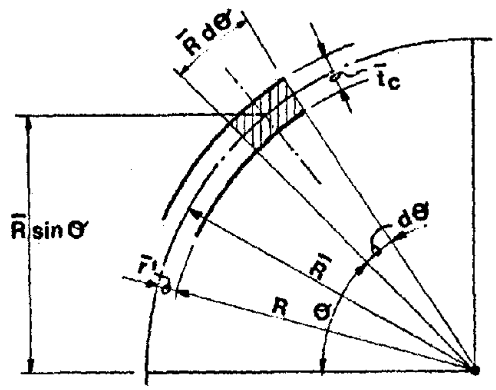
$$\bar{R} = R + \bar{r}'$$

For $\bar{R}d\theta = 12$ in.:

$$\bar{t}_c \bar{R} d\theta = 12t_c + (n_r - 1)\ A_y,$$

where t_c = mean core thickness for the composite pipe wall, from which

$$\bar{t}_c = t_c + \frac{(n_r - 1)A_y}{12}$$



DIFFERENTIAL ELEMENT FOR COMPOSITE PIPE WALL

FIG. 5

The moment of inertia of the composite section about its horizontal centroidal axis is:

$$I_x = 4\int_0^{\pi/2} (\bar{R}\ \sin\ \theta)^2 \bar{t}_c \bar{R}\ d\theta$$

$$= \pi\bar{R}^3 [t_c + \frac{(n_r - 1)A_y}{12}]$$

and since the composite area of the pipe per foot of circumference is:

$$A_{TC}/ft = 12t_c + (n_r - 1)A_y,$$

$$A_{TC} = A_{Tc}/ft.\ x\ 2\pi\bar{R}$$

and

$$I_x = \pi\bar{R}^3\ (A_{TC}/ft)/12.$$

The extensional stiffness of the composite section without the protective coating is, thus:

$$k_{x,p} = E_{cr}\ .\ A_{TC}/L = \frac{E_{cr}\ .\ A_{TC}/ft.}{L}\ \ x\ 2\pi\bar{R}/12\ ,$$

3. Elastic Properties and Periods of Unjointed Pipes

3a) Masses of a 20 ft length of Pipe:

For the 30" diameter PCC Pipe:

weight of pipe W_p = 325 lbs./l.f. (see Part IV, p.118)

weight of water W_w = 306 lbs./l.f. (see Part IV, p.118)

Unit Mass of the empty pipe $M_e = \frac{W_p \times L}{g}$,

where L = segment length in ft.

and g = acceleration of gravity - in/sec^2

$$M_e = \frac{325 \text{ lbs./l.f.} \times 20 \text{ ft}}{386.4 \text{ in/sec}^2} = 16.82 \text{ lb.sec}^2/\text{in.}$$

Mass of the pipe full of water $M_f = \frac{(W_p + W_w) \times L}{g}$,

$$M_f = \frac{(325 + 306) \text{ lbs./l.f.} \times 20 \text{ ft.}}{396.4 \text{ in/sec}^2} = 32.66 \text{ lb.sec}^2/\text{in.}$$

For the 60" diameter PCEC Pipe:

weight of pipe W_p = 1220 lbs./l.f. (see Part IV, p.141)

weight of water W_w = 1225 lbs./l.f. (see Part IV, p.141)

Mass of the empty pipe

$$M_e = \frac{1220 \text{ lbs./l.f.} \times 20 \text{ ft.}}{386.4 \text{ in/sec}^2} = 63.15 \text{ lb.sec}^2/\text{in.}$$

Mass of the full pipe

$$M_f = \frac{(1220 + 1225) \text{ lbs./ft.} \times 20 \text{ ft.}}{386.4 \text{ in/sec}^2} = 126.50 \text{ lb.sec}^2/\text{in.}$$

3b) Properties of Composite Pipe Ring

To determine the cracked and uncracked bounds for the elastic properties of the composite sections of the PCC and PCEC pipes, their cross-section has been drawn in Fig. 4 . A lower bound for axial compression and transverse bending stiffness is obtained by assuming that the protective coating is <u>entirely cracked</u>. Indicating by:

A = the area per lineal foot of circumference for each component of the composite pipe wall.

r' = the radial distance from the inside face of the concrete core to the centroid of the component.

$\bar{r}'$ = the mean radial distance from the inside face of the concrete core to the centroid of the composite pipe wall (see Fig. 4)

n_r = modular ratio for the pipe

one obtains:

PROPERTIES OF THE UNCRACKED COMPOSITE SECTION WITHOUT PROTECTIVE COATING			
COMPONENT	A	r'	A r'
Concrete Core	$12\, t_c$	$t_c/2$	$6\, t_c^2$
Steel Cylinder	$(n_r - 1)\, A_y$	t_{yr}	$(n_r - 1)\, A_y\ t_{yr}$
$A_{TC}/_{FT} = \Sigma A = 12\, t_c + (n_r - 1)\, A_y$		$\Sigma A r' = 6\, t_c^2 + (n_r - 1)\, A_y\ t_{yr}$	
$\bar{r}' = \frac{\Sigma A r'}{\Sigma A}$			

where A_{TC} = total transformed area of the composite pipe in.^{2}

L = Length of the segment (in.)

and E_{cr} = the effective modulus of elasticity (psi), (see Table IX, p.112)

An upper bound for the elastic characteristics of the composite pipe section in axial compression and transverse bending can be determined by assuming that the protective coating remains totally uncracked around the entire circumference.

The total thickness of the pipe wall with the protective coating is:

$$t_w = t_c + t_{wc} \quad \text{(see Fig. 4)}$$

We obtain:

PROPERTIES OF THE UNCRACKED COMPOSITE SECTION WITH PROTECTIVE COATING			
COMPONENT	A	r'	A r'
Concrete Core	$12\, t_w$	$t_w/2$	$6\, t_w^2$
Steel Cylinder	$(n_r - 1)\, A_y$	t_{yr}	$(n_r - 1)\, A_y\, t_{yr}$
$A_{TC/FT} = \Sigma A = 12\, t_w + (n_r - 1)\, A_y$		$\Sigma A r' = 6\, t_w^2 + (n_r - 1)\, A_y\, t_{yr}$	
$\bar{r}' = \frac{\Sigma A r'}{\Sigma A}$			

The extensional stiffness of the composite section with protective coating is:

$$k_{x,p} = \frac{E_{cr} \times A_{TC}}{L}$$

3c) Composite Area, Extensional Stiffness and Moment of Inertia for a 30" PCC Pipe without Protective Coating:

PROPERTIES OF THE UNCRACKED COMPOSITE SECTION WITHOUT PROTECTIVE COATING FOR A 30" PCC PIPE			
COMPONENT	A (in^2)	r' (in)	A r' (in^3)
Concrete Core	1.875 × 12 = 22.50	0.9375	21.094
Steel Cylinder	(5−1) .0610 (12)=2.928	1.8445	5.401
A_{TC}/ft = ΣA = 25.428 $\bar{r}' = \frac{26.495}{25.428} = 1.042$ in.			ΣAr' = 26.495

$$\bar{R} = R + \bar{r}$$

$$= 16.042 \text{ in.}$$

$$A_{TC} = \frac{2\pi R}{12} \times A = \frac{2\pi\ (16.042)}{12} \times 25.428$$

$$= 213.58 \text{ in.}^2$$

$$k_{x,p} = \frac{E_{cr}\ A_{TC}}{L} = \frac{5.6 \times 10^6 \text{psi} \times 213.58^{112}}{240} = 4.9836 \times 10^6 \text{ lbs/in.}$$

$$I_x = \pi \bar{R}^3 \quad (A_{TC}/\text{ft})/12 = \pi (16.042)^3 \times 2.119$$

$$= 27.482.5 \text{ in.}^4$$

3c,ii) Composite Area Extensional Stiffness and Moment of Inertia for a 30" PCC Pipe with Protecitve Coating:

PROPERTIES OF THE UNCRACKED COMPOSITE SECTION WITH PROTECTIVE COATING FOR A 30" PCC PIPE			
COMPONENT	$A\,(in^2)$	$r'\,(in)$	$Ar'\,(in^3)$
Concrete Core	12 × 2.6875 = 32.250	1.34375	43.336
Steel Cylinder	(5−1) .0610 (12) = 2.928	1.8445	5.401
$A_{TC}/ft = \Sigma A = .35.178$ $\bar{r}' = \frac{35.178}{48.737} = 1.385$ in.			$\Sigma Ar' = 48.737$

$$\bar{R} = R + \bar{r}' = 16.385 \text{ in.}$$

$$A_{TC} = 2\pi R = \frac{2\pi\ (16.385)}{12} \times 35.178 = 301.81 \text{ in.}^2$$

$$k_{x,p} = E_{cr} = \frac{5.6 \times 10^6 \text{psi} \times 30.181^{112}}{240} = 7.0421 \times 10^6 \text{ lbs./in.}$$

$$I_x = \pi\bar{R}^3 = \tau_c = \pi(16.385)^3 \times [t_c + \frac{(n_r - 1)A_y}{12}]$$

$$= \pi(16.385)^3(A_{TC}/ft)/12$$

$$= 40{,}511.6 \text{ in.}^4$$

3c,iii) <u>Composite Area, Extensional Stiffness and Moment of Inertia for a 60" PCEC Pipe without Protective Coating</u>:

$$t_{yr} + t_{cc} + t_y/2 = \left(\frac{63. - 60.}{2}\right) - \frac{0.0598}{2} = 1.470 \text{ in.}$$

PROPERTIES OF THE UNCRACKED COMPOSITE SECTION WITHOUT PROTECTIVE COATING FOR A 60" PCEC PIPE			
COMPONENT	$A(in^2)$	$r'(in)$	$Ar'(in^3)$
Concrete Core	4.50 × 12 = 54.000	2.25	121.500
Steel Cylinder	(6-1).0598(12)=3.588	1.470	5.275
$A_{TC}/ft = \Sigma A =$ 57.588; $\bar{r}' = \frac{126.775}{57.588} = 2.201$ in.			$\Sigma Ar' =$ 126.775

$$\bar{R} = R + \bar{r} = 32.201 \text{ in.}$$

$$A_{TC} = \frac{2\bar{R}}{12} \times A_{TC}/ft = 16.860 \times 57.588 = 970.957 \text{ in.}^2$$

$$k_{x,p} = \frac{E_{cr} \cdot A_{Tc}}{L} = \frac{4.7 \times 10^6 \times 970.957}{240.} = 19.015 \times 10^6 \text{ lbs./in.}$$

$$I_x = \bar{R}^3 \times \bar{t}_c = (32.201)^3 + \frac{57.588}{12}$$

$$503{,}394.8 \text{ in.}^4$$

3c,iv) Composite Area, Extensional Stiffness and the Moment of Inertia for a 60" PCEC Pipe with Protective Coating:

PROPERTIES OF THE UNCRACKED COMPOSITE SECTION WITH PROTECTIVE COATING FOR A 60" PCEC PIPE			
COMPONENT	$A\,(in^2)$	$r'\,(in)$	$Ar'\,(in^3)$
Concrete Core	12 × 5.375 = 64.500	2.6875	173.344
Steel Cylinder	(6-1).0598(12) = 3.588	1.470	5.275
$A_{TC}/ft = \Sigma A = 68.088$; $\bar{r}' = \frac{178.619}{68.088} = 2.623$ in.			$\Sigma Ar' = 178.619$

$$\bar{R} = R + \bar{r} = 32.623 \text{ in.}$$

$$A_{TC} = \frac{2\pi R}{12} \times A_{TC}/ft = \frac{2\pi(32.623)}{12} \times 68.088 = 1163.0 \text{ in.}$$

$$k_{x,p} = \frac{E_{cr} \cdot A_{Tc}}{L} = \frac{4.7 \times 10^6 \times 1163.0}{240.} = 22.775 \times 10^6 \text{ lbs./in.}$$

$$I_x = \pi\bar{R}^3 \times t_c = \pi(32.623)^3(A_{TC}/ft)/12$$

$$= \pi(32.623)^3 + 68.088/12$$

$$= 618{,}886.3 \text{ in.}^4$$

Extensional Periods of 30" pipe without the protective coating:

$k_{x,p} = 7.0421 \times 10^6$ lbs./in. (see p.185),

circular frequency of full pipe

$$\omega_{f,p} = \sqrt{\frac{k_{x,p}}{M_f}} = \frac{7.0421 \times 10^6}{32.66} = 464.34 \text{ sec}^{-1},$$

period of full pipe

$$T_{f,p} = \frac{2\pi}{\omega_{f,p}} = \frac{2\pi}{464.34} = 0.0135 \text{ sec.}$$

circular frequency of empty pipe :

$$\omega_{e,p} = \frac{7.0421 \times 10^6}{16.82} = 647.05 \quad sec^{-1}$$

period of empty pipe :

$$T_{e,p} = \frac{2\pi}{\omega_{e,p}} = \frac{2\pi}{647.05} = 0.0097 \quad sec$$

$$k_{x,p} = 4.9836 \times 10^6 \text{ lbs./in.}$$

circular frequency of full pipe :

$$\omega_{f,p} = \sqrt{\frac{k_{x,p}}{M_f}} = \frac{4.9836 \times 10^6}{32.66} = 390.63 \quad sec^{-1}$$

period of full pipe :

$$T_{f,p} = \frac{2\pi}{\omega_{f,p}} = \frac{2\pi}{390.63} = 0.0161 \text{ sec}$$

circular frequency of empty pipe:

$$\omega_{e,p} = \sqrt{\frac{k_{x,p}}{M_e}} = \frac{4.9836 \times 10^6}{16.82} = 544.33 \text{ sec}^{-1}$$

period of empty pipe:

$$T_{e,p} = \frac{2\pi}{\omega_{e,p}} = \frac{2\pi}{544.33} = 0.0115 \text{ sec}$$

<u>Extensional periods of the 60" PCEC pipe without the protective coating</u>:

The extensional stiffness = $k_{x,p} = 19.015 \times 10^6$ lbs./in (see p.186)

$$M_e = 63.15 \text{ lbs.sec}^2\text{/in.}$$

$$M_f = 126.5 \text{ lbs.sec}^2\text{/in.}$$

$$\omega_{f,p} = \sqrt{\frac{k_{x,p}}{M_f}} = \frac{19.015 \times 10^6}{126.5} = 388.47 \text{ sec}^{-1}$$

$$T_{f,p} = \frac{2\pi}{\omega_{f,p}} = \frac{2\pi}{388.47} = 0.016 \text{ sec}$$

$$\omega_{e,p} = \sqrt{\frac{k_{x,p}}{M_e}} = \frac{19.015 \times 10^6}{63.15} = 548.73 \text{ sec}^{-1}$$

the period of the empty pipe is:

$$T_{x,p} = \frac{2\pi}{\omega_{e,p}} = \frac{2\pi}{548.73} = 0.012 \text{ sec}$$

Extensional periods of 60" PCEC pipe with the protective coating:

$$k_{x,p} = 22.775 \times 10^6 \text{ lbs./in.}$$ (see p. 187)

$$\omega_{f,p} = \sqrt{\frac{k_{x,p}}{M_f}} = \frac{22.775 \times 10^6}{126.5} = 424.31 \text{ sec}^{-1}$$

$$T_{f,p} = \frac{2\pi}{\omega_{f,p}} = \frac{2\pi}{424.31} = 0.015 \text{ sec}$$

$$\omega_{e,p} = \sqrt{\frac{k_{x,pp}}{M_e}} = \frac{22.775 \times 10^6}{63.15} = 600.54 \text{ sec}^{-1}$$

$$T_{e,p} = \frac{2\pi}{\omega_{e,p}} = \frac{2\pi}{600.54} = 0.011 \text{ sec}$$

3d) A lowest bound for the axial tension can be calculated by assuming that all the concrete has cracked and only the steel cylinder is effective.

Area of the steel cylinder $A_{yT} = A_y \times 2\pi R_c/12$

where R_c = average radius of cylinder = $R + t_{yr}$

tensile extensional stiffness of the pipe $k_{x,p} = E_s A_{yT}/L$

where E_s = the modulus of elasticity of the steel

i) <u>Cylinder area, tensile extensional stiffness, and periods of a 30" PCC pipe</u>

$$A_{yT} = (\frac{0.732}{12}) \times 2\pi(16.8445) \quad R_y = 15.0 + 1.8445 = 16.8445 \text{ in.}$$

$$= 6.456^{(in^2)} \quad in^2$$

$$k_{x,p} = \frac{28.0 \times 10^6 \times 6.456}{240.} = 0.7532 \times 10^6 \text{ lb/in. (in tension)}$$

$$M_e = 16.82 \text{ lbs.sec}^2\text{/in.}$$

(see p. 179)

$$M_f = 32.66 \text{ lbs.sec}^2\text{/in.}$$

$$\omega_{f,p} = \sqrt{\frac{k_{x,p}}{M_f}} = \sqrt{\frac{0.7532 \times 10^6}{32.66}} = 151.86 \text{ sec}^{-1}$$

$$T_{f,p} = \frac{2\pi}{\omega_{f,p}} = \frac{2\pi}{151.86} = .041 \text{ sec}$$

$$\omega_{e,p} = \sqrt{\frac{k_{x,p}}{M_e}} = \frac{0.7532 \times 10^6}{16.82} = 211.61 \text{ sec}^{-1}$$

$$T_{e,p} = \frac{2\pi}{\omega_{e,p}} = \frac{2\pi}{211.61} = 0.030 \text{ sec}$$

ii) <u>Cylinder area and tensile extensional stiffness and periods of 60" PCEC pipe</u>

For the 60" PCC Pipe with only the steel cylinder effective in resisting longitudinal strain:

the extensional stiffness of the pipe in tension [neglecting the entire concrete core (see discussion of this above)] with:

$$R_c = R + t_{yr} = 30.0 + 1.470$$
$$= 31.470 \text{ in.}$$

$$A_{yT} = A_y \times \frac{2\pi R_c}{12}$$

$$= \left(\frac{0.7176}{12}\right) \times 2\pi(31.470) = 11.824 \quad in^2 ,$$

is: $$k_{x,p} = \frac{28.0 \times 10^6 \times 11.824}{240.} = 1.3795 \times 10^6 \text{ lbs./in. (in tension):}$$

$M_e = 63.15$ lbs.sec^2/in.

(see p. 179)

$M_f = 126.50$ lbs.sec^2/in.

$$\omega_{f,p} = \sqrt{\frac{k_{x,p}}{M_f}} = \sqrt{\frac{1.3795 \times 10^6}{126.50}} = 104.4 \text{ sec}^{-1}$$

$$T_{f,p} = \frac{2\pi}{\omega_{f,p}} = \frac{2\pi}{104.4} = 0.060 \text{ sec}$$

$$\omega_{e,p} = \sqrt{\frac{k_{x,p}}{M_e}} = \sqrt{\frac{1.3795 \times 10^6}{63.15}} = 147.8 \text{ sec}^{-1}$$

$$T_{e,p} = \frac{2\pi}{\omega_{e,p}} = \frac{2\pi}{147.8} = 0.043 \text{ sec}$$

3e) For longitudinal bending, a <u>lower</u> bound for the <u>elastic cracked section</u> is calculated by assuming no effective concrete in the tensile zone below the neutral axis of the pipe.

The pipe model used in arriving at an expression for the cracked moment of inertia has been reproduced in Fig. 6 from the currently proposed AWAA Manual M9 (Ref. 2, Part I) which is in draft format presently. The transcendental equation for the tangent of the angle α subtended by the neutral axis is:

$$\tan \alpha = \alpha + \frac{np\pi}{1-p} \; ; \text{ where } p = t_s/t_w \quad \text{(see Fig. 6)}$$

The formula for the moment of inertia of the cracked section is also given in the proposed AWAA Manual M9:

$$I_x = 2R_c^{\,3}\, t_w[(1-p)(\frac{\alpha}{2} + \alpha\cos^2\alpha - \frac{3}{4}\sin 2\alpha) + np\pi(\frac{1}{2} + \cos^2\alpha)],$$

where $R_c = R + t_{yr}$

R = radius to the innerface of the concrete core

and t_{yr} = radial distance from innerface of the core to the center of the steel cylinder (see Fig. 4).

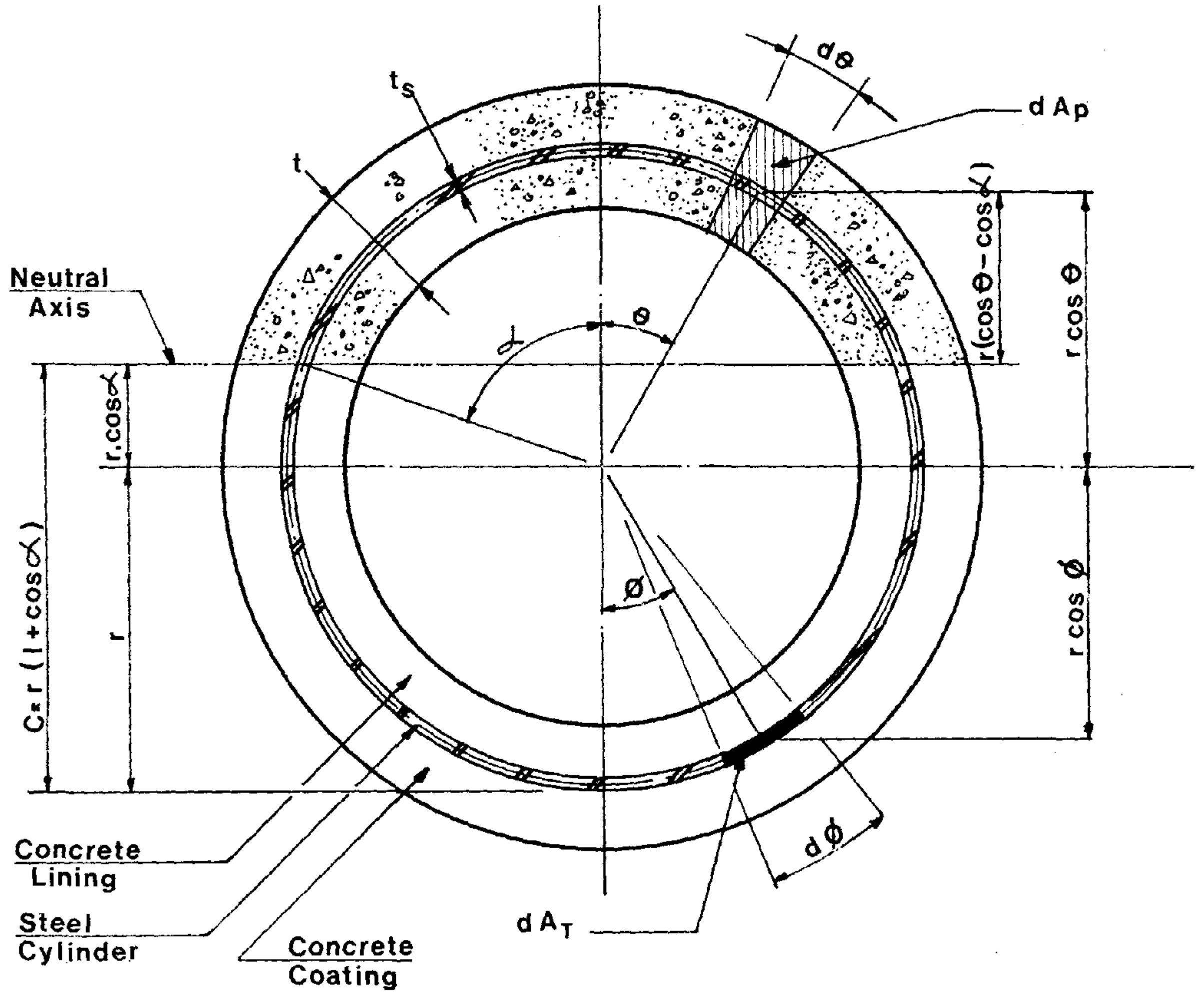
<u>For a 30" PCC pipe</u>:

$$\tan \alpha = \alpha + \frac{np\pi}{1-p} \quad p = t_s/t_w = \frac{0.0610}{2.6875} = 0.0227$$

$$n = 5 \quad \text{(centrifugated conc.)}$$

(for derivation see revised AWAA Manual M9, Chapt. 8 pp. 122-124)

$$\frac{np\pi}{1-p} = \frac{5(0.0277)\ \pi}{(1-\ 0.0227)} = 0.3648$$



PIPE MODEL FOR HOLLOW CIRCULAR TUBE

(ELASTIC CRACKED SECTION FOR LONGITUDINAL BENDING)

FIG. 6

r = Outside radius of steel cylinder, (in.)

t = Total pipe thickness with coating (in.)

t_c = Thickness of concrete lining and coating, (in.)

t_s = Thickness of steel cylinder, (in.)

Area of concrete = $t_c rd\theta$

Area of steel = $t_s rd\theta$, or $t_s rd\phi$

$p = \frac{t_s}{t}$, or $t_s = pt$

and,

Area of steel = $ptrd\theta$, or $ptrd\phi$

$dA_p = t[1+(n-1)p]rd\theta$; $dA_T = nptrd\phi$

$$\tan\alpha - \alpha - 0.3648 = 0$$

Solving by Newton's method of tangents:

$$f(\alpha) = \tan\alpha - \alpha - 0.3648$$

$$f'(\alpha) = \sec^2\alpha - 1 = \tan^2\alpha$$

$$\alpha_1 = \alpha_o - \frac{f(\alpha_o)}{f'(\alpha_o)}$$

$$\alpha_o = 45°$$

$$\alpha = \alpha_3 = 51.7333° = 0.0929 \text{ radians}$$

$$\sin\alpha = 0.7851$$

$$\cos\alpha = 0.6193$$

$$\cos^2\alpha = 0.3836.$$

The moment of inertia of the cracked section for the hollow tube is:

$$I_x = 2R_c^{\,3}\ t_w[(1-p)(\frac{\alpha}{2} + \cos^2\alpha - \frac{3}{4}\sin 2\alpha) + np\pi(\frac{1}{2} + \cos^2\alpha)]$$

$$R_c = R + t_{yr}$$

$$= 15.0 + 1.8445 = 16.8445 \text{ in.}$$

$$I_x = 2(16.8445)^3 \times 2.6875[0.9773\{0.4515 + 0.9029(0.3836) - 0.75(0.9725)\}$$

$$+ 5(.0227)\pi(0.50 + 0.3836)]$$

$$= 9{,}813.30 \text{ in.}^4$$

<u>For a 60" PCEC pipe</u>:

$$p = t_s/t_w = \frac{0.0598}{5.735} = 0.01113 \ ; \quad n = 6 \text{ (cast-in-place concrete)}$$

$$\frac{np\pi}{(1-p)} = \frac{6(0.01113)\ \pi}{0.98887} = 0.2122$$

$$\tan\alpha - \alpha - 0.2122 = 0$$

Solving by Newton's method of tangents (see Ref. 4).

$\alpha = \alpha_3 = 44.8617° = 0.7830$ radians

$\sin\alpha = 0.7054$

$\cos\alpha = 0.7088$

$\cos^2\alpha = 0.5024 \qquad \sin 2\alpha = 0.99999$

$p = 0.01113$

$(1-p) = 0.98887$

$R_c = R + t_{yr} = 30.0 + 1.470 = 31.47$ in.; $\quad t_w = t_c + t_{wc}$

$$I_{x_{cr}} = 2R_c^3 t_w[(1-p)(\frac{\alpha}{2} + \alpha\cos^2\alpha - \frac{3}{4}\sin 2\alpha) + np\pi(\frac{1}{2} + \cos^2\alpha)]$$

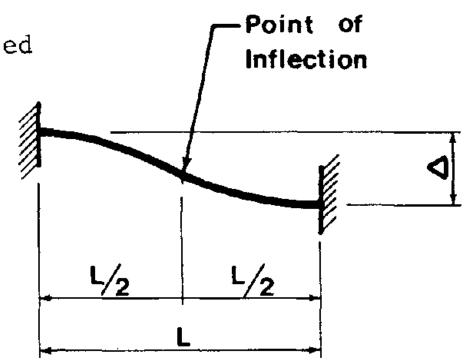
$$= 2(31.47)^3 x\ 5.375[0.98887\{0.3915 + 0.7830(0.5024) - 0.75(0.99999)\}$$

$$+ 6(0.01113)\ ().50 + 0.5024)]$$

$I_x = 83{,}535.9$ in.^{4}

<u>Periods of transverse bending motion for cracked sections</u>:

For the transverse bending mode the displaced shape of a pipe of length L is given in Fig. 7.



MODE SHAPE FOR TRANSVERSE BENDING

Fig. 7

The frequency of this fundamental mode may be obtained by taking half the segment as a cantilever beam with a uniform load. (see Ref. 28, part IV).

$$f = \frac{3.89}{\sqrt{\dfrac{\omega_{f,p \atop e,p} (L/2)(L/2)^3}{8EI}}}$$

The period is:

$$T_{f,p} = \frac{1}{f} = \frac{L^2}{44.010} \sqrt{\frac{\omega_{f,p \atop e,p}}{EI_x}}$$

For a 20' length of pipe:

$$T_{f,p \atop e,p} = \frac{(20 \times 12)^2}{44.010} \sqrt{\frac{\omega_{f,p \atop e,p}}{EI_x}}$$

$$= 1308.794 \sqrt{\frac{\omega_{f,p \atop e,p}}{EI_x}}$$

The periods of the full and empty pipe are given on the next page (196a).

PART V 3.

ELASTIC - UNJOINTED CONCRETE PIPES

TRANSVERSE BENDING MODE - PIPE PERIODS FOR FULL AND EMPTY PIPES (CALCULATIONS)

TYPE OF PIPE	PIPE WEIGHTS FULL - W_f EMPTY - W_e MOD. OF ELAST.-E_{cr}	STIFFNESS AND PROPERTIES ASSUMPTIONS	I_x (IN^4)	$\frac{W_f/12}{EI_x}$ (IN^{-3})	$T_f = 1308.794\sqrt{\frac{W_f/12}{EI_x}}$ (SEC.)	$T_e = \sqrt{\frac{W_e}{W_f}} \times T_f$ (SEC.)
PCC 30" DIAM 20' LGTH	W_f = 631 lbs/ft. W_e = 325 lbs/ft. $\sqrt{\frac{W_e}{W_f}}$ = 0.7176 E_{cr} = 5.6×10^6 psi	CONCRETE CORE + STEEL CYLINDER + PROTECTIVE COVER	40,511.6	$2,3178 \times 10^{-10}$	0.020	0.014
		CONCRETE CORE + STEEL CYLINDER	27,482.5	3.4166×10^{-10}	0.024	0.017
		CIRCULAR BEAM CRACKED SECTION FOR BENDING	9,813.3	9.5685×10^{-10}	0.041	0.029
PCEC 30" DIAM 20' LGTH	W_f = 2444 lbs/ft. W_e = 1220 lbs/ft. $\sqrt{\frac{W_e}{W_f}}$ = 0.7065 E_{cr} = 4.7×10^6 psi	CONCRETE CORE + STEEL CYLINDER + PROTECTIVE COVER	618,886.3	7.0018×10^{-11}	0.01095	0.0077
		CONCRETE CORE + STEEL CYLINDER	503,394.8	8.6082×10^{-11}	0.01214	0.0086
		CIRCULAR BEAM CRACKED SECTION FOR BENDING	83,535.9	5.1874×10^{-10}	0.030	0.021

PART V 3

ELASTIC - UNJOINTED CONCRETE PIPES

TYPE OF PIPE	STIFFNESS AND PROPERTIES ASSUMPTIONS	EXTENSIONAL MODE			TRANSVERSE BENDING MODE		
		STIFFNESS	PERIODS - FULL & EMPTY		STIFFNESS	PERIODS - FULL & EMPTY	
		K_x (#/")	$T_{x,f}$ (sec.)	$T_{x,e}$ (sec.)	K_φ (#/")	$T_{\varphi,f}$ (sec.)	$T_{\varphi,e}$ (sec.)
PCC 30" DIAM 20' LGTH	CONCRETE CORE + STEEL CYLINDER + PROTECTIVE COVER	7.0421×10^6	0.0135	0.0097	196.936×10^3	0.020	0.014
	CONCRETE CORE + STEEL CYLINDER	4.9836×10^6	0.0161	0.0115	133.595×10^3	0.024	0.017
	STEEL CYLINDER ONLY CRACKED SECTION FOR TENSION	0.7532×10^6	0.041	0.030			
	CIRCULAR BEAM CRACKED SECTION FOR BENDING				47.703×10^3	0.041	0.029
PCEC 60" DIAM 20' LGTH	CONCRETE CORE + STEEL CYLINDER + PROTECTIVE COVER	22.775×10^6	0.015	0.011	252.485×10^4	0.011	0.0077
	CONCRETE CORE + STEEL CYLINDER	19.015×10^6	0.016	0.012	205.383×10^4	0.012	0.0086
	STEEL CYLINDER ONLY CRACKED SECTION FOR TENSION	1.3795×10^6	0.060	0.043			
	CIRCULAR BEAM CRACKED SECTION FOR BENDING				340.815×10^3	0.030	0.021

TABLE I

PART V 3

PERIODS OF VIBRATION DUE TO LONGITUDINAL WAVE - ELASTIC CONT. PIPE

TYPE OF PIPE	SERVICE CONDITION	$T_{x,T}$ (sec.) Tension Phase	$T_{x,C}$ (sec.) Comp. Phase	$T_x = \frac{1}{2}(T_{x,T} + T_{x,C})$ (sec.)
PCC 30" DIAM 20' LGTH	FULL	0.041	0.0135	0.0273
	EMPTY	0.030	0.0097	0.0199
PCEC 60" DIAM 20' LGTH	FULL	0.060	0.0150	0.0375
	EMPTY	0.043	0.0110	0.0270

TABLE II

PART V 4

RUBBER GASKETED JOINTED CONCRETE PIPES

TYPE OF PIPE	WORKING PRESSURE	EXTENSIONAL MODE			ROTATIONAL MODE		
		STIFFNESS	PERIODS- FULL & EMPTY		STIFFNESS	PERIODS-FULL & EMPTY	
		K_x (#/")	$T_{x,f}$ (sec.)	$T_{x,e}$ (sec.)	K_φ ("-#/Rad)	$T_{\varphi,f}$ (sec.)	$T_{\varphi,e}$ (sec.)
PCC 30" DIAM 20' LGTH	150 PSI	32.627 x 10^3	0.199	0.143	194.161 x 10^5	1.143	0.820
PCEC 60" DIAM 20' LGTH	150 PSI	25.837 x 10^3	0.440	0.311	525.012 x 10^5	1.416	1.000

1. ABOVE VALUES BASED ON 20°F AMBIENT PIPE TEMPERATURE.
2. GASKET DEFLECTION DUE TO INSTALLATION ASSUMED TO EQUAL 35%; GASKETS TO UNDERGO A 20% STRESS RELAXATION AFTER 20 YEARS.
3. A NO INTERFERENCE CONDITION IS ASSUMED AT THE JOINT (NO STEEL TO STEEL BINDING).

TABLE III

4. PROPERTIES AND PERIODS FOR THE RUBBER-GASKETED JOINTED PIPE

a) The behavior of the rubber-gasketed joints in the PCC and PCEC pipes is complex and is influenced by the following parameters:

(a) Details of the confined gasket and, hence, of the type of bell and spigot, type of groove and type of gasket.

(b) Level of hydrostatic operating pressure, which in practice varies from 0 to 350 psi.

(c) Type of construction classification including:

a) the type and size of bedding and support, and

b) the soil environment and its interaction with the pipe, if any.

(d) Practical tolerances, which are a function of the size and the type of pipe.

(e) The depth of earth cover, which may influence both the friction between pipe and soil and the binding action between bell and spigot around the circumference of the pipe.

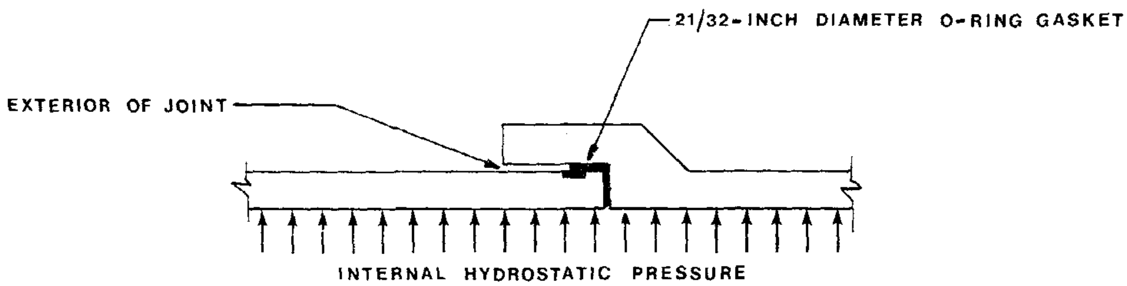
(f) The patterns of variation of the binding action between bell and spigot around the circumference of the pipe, including the randomness of the binding action.

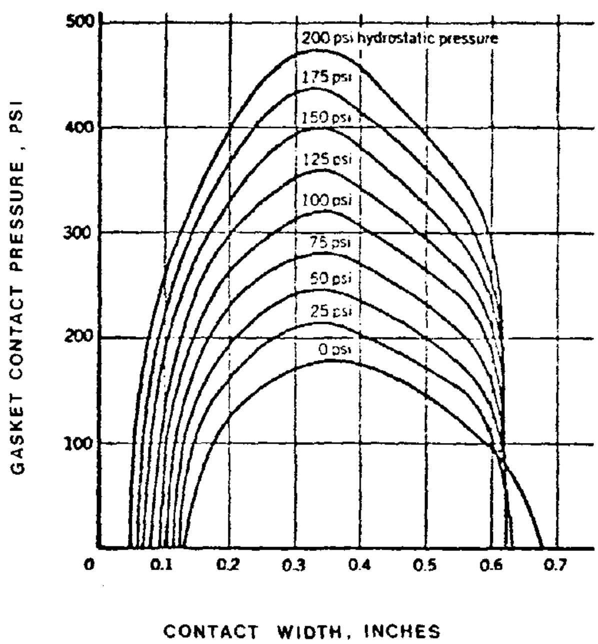
For an installed joint in the field, the extensional and rotational characteristics of the joint are a function of the friction force between the gasket and the bell, the binding friction between the bell-and-spigot (if it exists) and the effectiveness of joint grouting in resisting tensile and compressive stresses and strains.

The friction force between the gasket and the bell is a function of the compressive contact pressure and the coefficient of friction between the two surfaces. As both the contact pressure and hence the frictional force vary across the width of the spigot groove (for details of the groove see Fig. 16A and 16B, Part II, p.23),

the actual pressure bulb shape and the resultant forces are complex. A discussion of the complexities of a theoretical analysis of this problem for the bell-and-spigot used in reinforced concrete pipes is given in Ref. 2. The contact pressure bulb shape for the rubber gasket is a function of the internal pressure in the pipe. Pressure measurements between the gasket and the bell ring have been made on scaled plexiglass models by Valenziano (see Ref. 3). These tests had the purpose of determining the compressive contact pressure between the gasket and the bell under varying static internal pressures up to 200 psi and for the spigot shape used in the PCC and PCEC pipes. The initial compressive strain in the gasket, measured by the industry as a percent of the stretched O-ring diameter and called gasket deflection, is also a parameter in these tests. An article in the Nov., 1967 AWWA Journal by Frank P. Valenziano (see Ref. 3, part V) shows the peak gasket contact pressure to be 400 psi, for an internal pressure of 150 psi for a 64 durometer gasket material and a gasket deflection of 28.3 percent. A diagram showing an isolated detail of the joint and the contact pressure bulb shapes as measured by Valenziano appears in Fig. 8.

Conversations with the leading PCC and PCEC pipe and gasket manufacturers, has established that the usual range of gasket deflections in these pipes is between 36 and 37 percent. Using Fig. 8 and with a linear relationship between the internal pressure and the contact width (see Ref. 3),results in a peak gasket contact pressure of approximately 430 psi for an internal pressure of 150 psi. To represent the actual field condition of the gasket, a reduction of 20 percent for stress relaxation after 20 years was used. This results in an effective long-term peak contact pressure for the PCC and PCEC pipes in the field of 364 psi. This corresponds,





CONTACT PRESSURE, 64 DUROMETER

FROM RUBBER-GASKET JOINTS FOR CONCRETE PIPES
JOURNAL AWWA NOV. 1967 BY FRANK P. VALENZIANO

FIG. 8

approximately, to the 125 psi internal pressure bulb curve for contact pressure across the groove shown in Fig. 8. Integrating this 125 psi pressure bulb curve over the groove width and dividing by the groove width of 3/4 inch gives a mean effective contact pressure of 215 psi for a hydrostatic pressure of 150 psi for a pipe that has been in the ground for 20 years.

b. MAXIMUM PULL-OUT UNGROUTED-JOINT FORCE:

The maximum pull-out ungrouted-joint force per unit length may be expressed as a function of the mean contact pressures and the coefficients of friction across the bearing surfaces at the gasketed joint by the following simplified equation.

$$F_f = \mu_s W_{sb} \sigma_{sc} + \mu_g W_g \sigma_{gc}$$

where μ_g = mean coefficient of friction for the rubber gasket on the steel bell ring = 0.70

W_g = the width of the compressed gasket = 0.75 in.

σ_{gc} = the mean effective gasket contact pressure = 215 psi for an internal pressure of 150 psi

μ_s = mean coefficient of friction between the steel surfaces of the bell and spigot = 0.40

W_{sb} = the width of steel to steel bearing between bell and spigot = 0.50 in.

σ_{sc} = the mean effective contact pressure between the bell and the spigot where steel to steel binding exists (called interference by the industry)

Conversations with the American Concrete Pipe Association and leading manufacturers disclosed that binding has probably a random distribution, and that no measurements have been taken to establish the magnitudes and distributions of the steel binding contact pressures. Therefore, for purposes of establishing a lower bound, we have assumed that no binding occurs ($\sigma_{sc} = 0$), and that only the gasket contact pressure is active in resisting joint extensions in the ungrouted joint.

For a working pressure of 150 psi,

$$F_f = 0.40x0.50x0 + 0.70x0.75x215 = 112.88 \text{ lbs/in.}$$

The gasket pull-out force due to friction for the ungrouted joints of the PCC and PCEC pipes with no interference is:

$$F_x = F_f \times \pi \times D_g,$$

where $D_g = D_y + 2t_g$

and t_g = approximate average thickness of the compressed gasket = 0.375 in. (see Fig. 16A, part II for details).

For the 30" PCC pipe:

$$D_g = D_y + 0.75 = 34.5 \text{ in}$$

and $F_x = 112.88 \times \pi \times 34.5 = 12,235$ lbs.

For the 60" PCEC pipe:

$$D_g = D_y + 0.75 = 63.75 \text{ in}$$

and $F_x = 112.88 \times \pi \times 63.75 = 22,607$ lbs.

In the actual pipeline the rubber-gasketed joints are grouted with concrete or cement mortar after the joint connection has been made. Based on actual field experience in breaking such joints apart, a major manufacturer has recommended that

300 psi be used for the value of the maximum tensile strength of the mortar. Using this value, the maximum extensional tensile joint force for the grouted joint is:

$$F_{xm} = F_x + 2\pi R_{cm} \times t_m \times 300 \text{ psi}$$

where the average radius to the centroid of the grouted mortar is:

$$R_{cm} = R + t_c/2$$

and the effective thickness of the grout is: $t_m = t_c - (1/2 + 9/16) = t_c - 1\ ^1/16$ in.

For the 30" PCC pipe:

$$R_{cm} = 15.0 + \frac{1.875}{2} = 15.9375 \text{ in}$$

$$t_m = 1.875 - 1.0625 = 0.8125 \text{ in}$$

$$F_{xm} = 12{,}235 + 2\pi x 15.9375 \times 0.8125 \times 300 = 36{,}645 \text{ lbs.}$$

For the 60" PCEC pipe:

$$R_{cm} = 30.0 + \frac{4.5}{2} = 32.25 \text{ in}$$

$$t_m = 4.5 - 1.0625 = 3.438 \text{ in}$$

$$F_{xm} = 22{,}607 + 2\pi x 32.25 \times 3.438 \times 300 = 231{,}570 \text{ lbs.}$$

C. <u>Extensional Deformations and Stiffness:</u>

For a 30" PCC pipe at a working pressure of 150 psi, assuming a linear relationship between force and displacement at leakage:

$$F_x = k_{x,g}\ \Delta_{max}$$

where

Δ_{max} = maximum extension = E = 0.375 in (see Table VIII, Fig. 17, Part II, p. 24)

and $k_{x,g}$ = average extensional stiffness at leakage

Therefore:

$$k_{x,g} = F_x/\Delta_{max} = \frac{12,235}{0.375} = 32.6267\times10^3 \text{ lbs/in}$$

Assuming the protective coating has cracked due to the action of a seismic wave, the deformation before the cement mortar becomes ineffective is:

$$\Delta_{m_{max}} = \frac{F_{xm}}{k_{x,p}} = \frac{36,645}{4.984\times10^6} = 0.0074 \text{ in,}$$

where $k_{x,p}$ is given in Table I.

For a 60" PCEC pipe at a working pressure of 150 psi, $\Delta_{max} = E = 0.875$ in, see Table VII Fig. 17, Part II p.24

$$k_{x,g} = F_x/\Delta_{max} = \frac{22,607}{0.875} = 25.837\times10^3 \text{ lbs/in,}$$

the deformation at the limit of the cement mortar cracking is:

$$\Delta_{m_{max}} = \frac{F_{xm}}{k_{x,p}} = \frac{231,570}{19.015\times10^6} = 0.0122 \text{ in}$$

d) Maximum Compressive Force and Deformation for the Grouted Pipe Joint.

Assuming that the outer protective coating cracks under the action of a seismic shear wave:

For the 30" PCC pipe,

the maximum compression joint force $= P_{jc} = A_{TC} \times f'_c = 213.58^2 \times 6000 = 1,281,500$

the maximum compressive joint extension $= \Delta_{c_{max}} = \frac{P_{jc}}{k_{x,p}} = \frac{1,281,500}{4.984\times10^6} = 0.2571$ in

For the 60" PCEC pipe,

the maximum compressive joint force $= P_{jc} = A_{TC} x f'_c = 970.96^2 \times 5,000 = 4,854,800$ lbs

the maximum compressive joint extension $= \Delta_{c_{max}} = \frac{P_{jc}}{k_{x,p}} = \frac{4,854,800}{19.015\times10^6} = 0.2553$ in.

e) Maximum Joint Force, $F_{f,m}$.

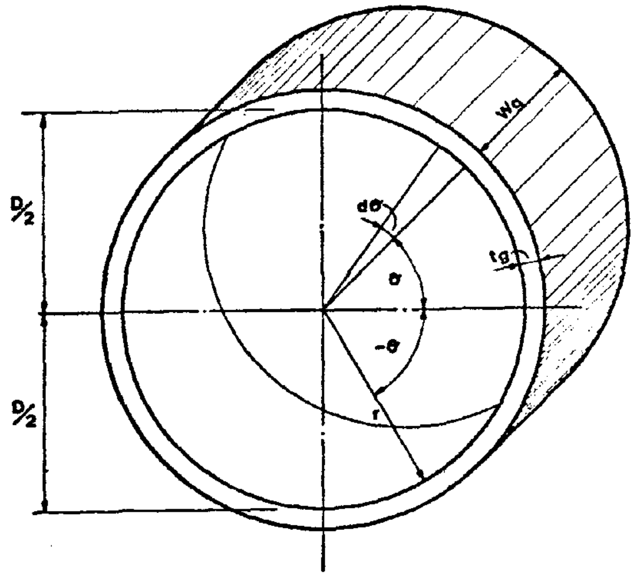
For a 30" PCC grouted pipe joint under a working pressure of 150 psi

$$F_{f,m} = F_f + F_m = 112.88 + 0.8125x300 = 356.63 \text{ lbs/lin.in.}$$

(where F_f = 112.88 lbs/in and $F_m = t_m$x300 lbs/in)

For a 60" PCEC grouted pipe joint under a working pressure of 150 psi

$$F_{f,m} = F_f + F_m = 112.88 + 3.438x300 = 1144.28 \text{ lbs/lin.in.}$$



SCHEMATIC MODEL OF COMPRESSED GASKET
FIG. 9

f) Joint Moments for the Gasketed Pipe:

Using the schematic model of the compressed gasket shown in Fig. 9, the moment for the ungrouted joint is:

$$M_j = 2\int_{-\pi/2}^{\pi/2} F_f \frac{D_g}{2} (1+\sin\theta) \frac{D_g}{2} d\theta = \frac{\pi}{2} F_f D_g^2$$

Similarly, for the grouted joint, assuming that the moment arm for the grout is approximately the same as that of the gasket, the moment at the joint is:

$$M_{mj} = \frac{\pi}{2} F_{f,m} D_g^2$$

Therefore, for the 30" PCC pipe at a working pressure of 150 psi:

$$M_j = \frac{\pi}{2} \times 112.88 \times (34.5)^2 = 211{,}045 \text{ lb-in}$$

and $$M_{mj} = \frac{\pi}{2} \times 356.63 \times (34.5)^2 = 666{,}770 \text{ lb-in}$$

For the 60" PCEC pipe at a working pressure of 150 psi:

$$M_j = \frac{\pi}{2} \times 112.88 \times (63.75)^2 = 720{,}605 \text{ lb-in}$$

and $$M_{mj} = \frac{\pi}{2} \times 1144.28 \times (63.75)^2 = 7{,}304{,}871 \text{ lb-in}$$

g) <u>Joint Rotations at the Cracking of the Grout.</u>

For the 30" PCC pipe, with a maximum mortar tension f_{tm} = 0.300 ksi

the maximum elongation $= \Delta_{max} = \dfrac{f_{tm} x L}{E_{cr}} = \dfrac{0.30x\ \ 240}{5.6x10^3} = .0129$ in,

the maximum rotation for cracking of mortared joint:

$$\phi_{max} = \frac{\Delta_{max}}{D_g} = \frac{.0129}{34.50} = 0.0004 \text{ radians} = .021 \text{ degrees.}$$

For the 60" PCEC pipe:

$$\Delta_{max} = \frac{f_{tm} x L}{E_{cr}} = \frac{0.30\ x\,240}{4.7x10^3} = .0153 \text{ in}$$

$$\phi_{max} = \frac{\Delta_{max}}{D_g} = \frac{.0153}{63.75} = .00024 \text{ radians} = .014 \text{ degrees.}$$

h) <u>Rotational Stiffnesses at Leakage for a Working Pressure of 150 psi.</u>

The rigid-body joint rotational stiffness at leakage is: $k_\phi = \dfrac{M_j}{\theta}$,

where the rotation at leakage $= \theta = \Delta_{max}/D_g = E/D_g$ where E = maximum extension at the joint at leakage

$$k_\phi = M_j/(E/D_g) = \frac{\pi}{2}\frac{F_f}{E} D_g^{\ 3}$$ (see Table VIII, Fig.17, Part II p. 24)

For the 30" PCC pipe:

$$\theta = E/D_g = 0.375/34.50 = 0.011 \text{ radians} = 0.62 \text{ degrees,}$$

$$k_\phi = \frac{\pi}{2}\ \frac{F_f}{E}\ D_g^{\ 3} = \frac{\pi}{2}\left(\frac{112.88}{0.375}\right)(34.5)^3 = 19{,}416{,}140 \text{ in-lbs/rad.}$$

For the 60" PCEC pipe:

$$\theta = E/D_g = 0.875/63.75 = 0.014 \text{ radians} = 0.79 \text{ degrees,}$$

$$k_\phi = \frac{\pi}{2} x \frac{F_f}{E}\ D_g^{\ 3} = \frac{\pi}{2}\left(\frac{112.88}{0.875}\right)(63.75)^3 = 52{,}501{,}220 \text{ in-lbs/rad.}$$

i) Graphs of Joint Behavior in the field.

Using the values calculated in the preceding pages, the extensional behavior of the rubber gasketed grouted joint has been graphically shown in Fig. 10 and 11 for the PCC and PCEC pipes. The rotational behavior of the rubber gasketed grouted joint has been graphically shown in Figs. 12 and 13 for the PCC and PCEC pipes. These graphs are self-explanatory and show the complexity of the behavior of the grouted rubber-gasketed joints used in PCC and PCEC underground pipelines. It should be noted that these graphs assume no interference and thus represent a lower bound for joint behavior.

j) Extensional Periods for the Rubber-Gasketed Pipes.

$$T_{\substack{f,g \\ e,g}} = 2\pi \sqrt{\frac{M_{f,e}}{k_{x,p}}}$$

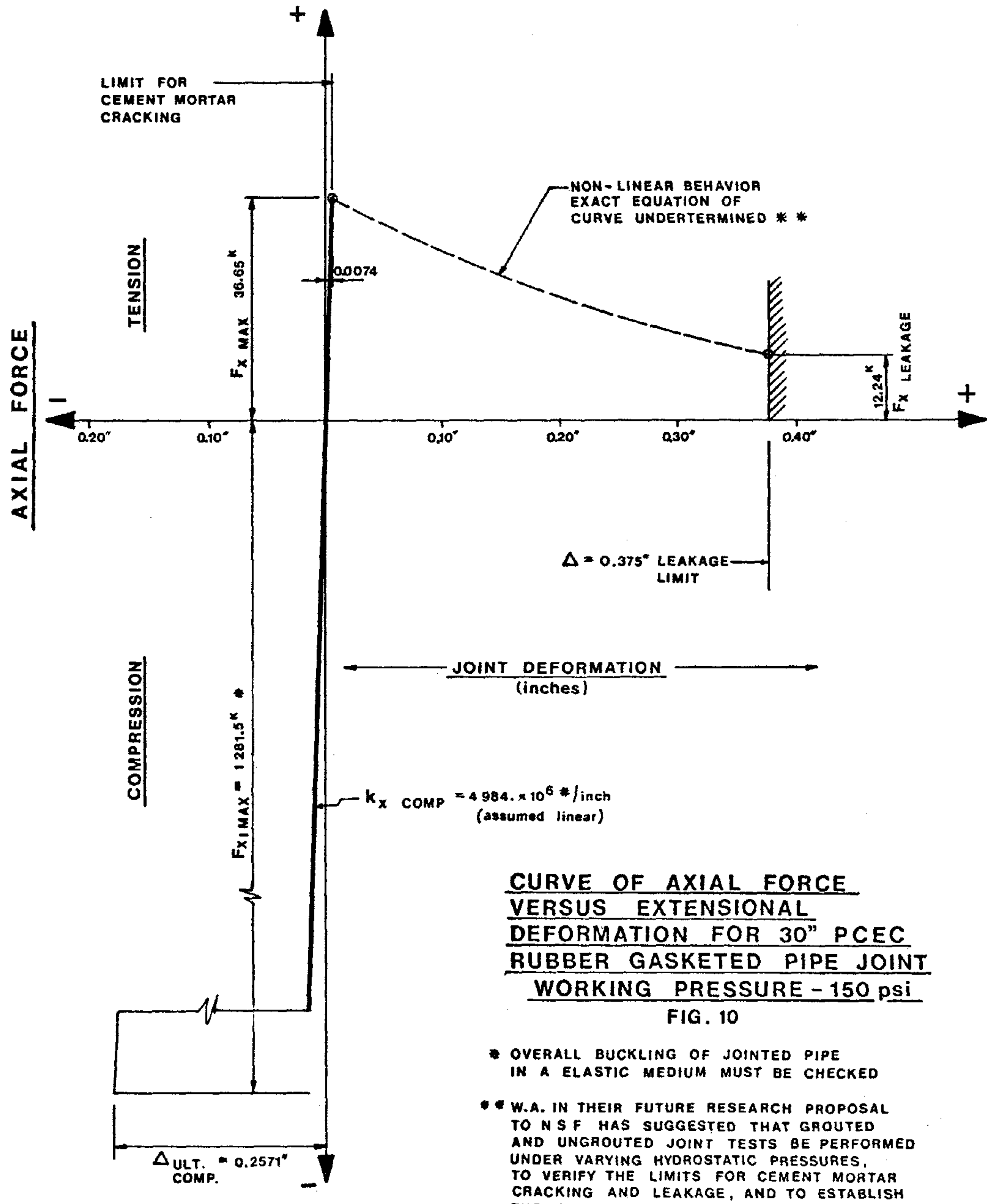
For the 30" PCC pipe at a working pressure of 150 psi, with:

M_f = 32.66 lbs-sec^2/in-and

M_e = 16.82 lbs-sec^2/in (see Part V,3. p. 179)

$$T_{f,g} = 2\pi \sqrt{\frac{32.66}{32.627\text{x}10^3}} = 0.199 \text{ sec.}$$

$$T_{e,g} = 2\pi \sqrt{\frac{16.82}{32.627\text{x}10^3}} = 0.143 \text{ sec.}$$

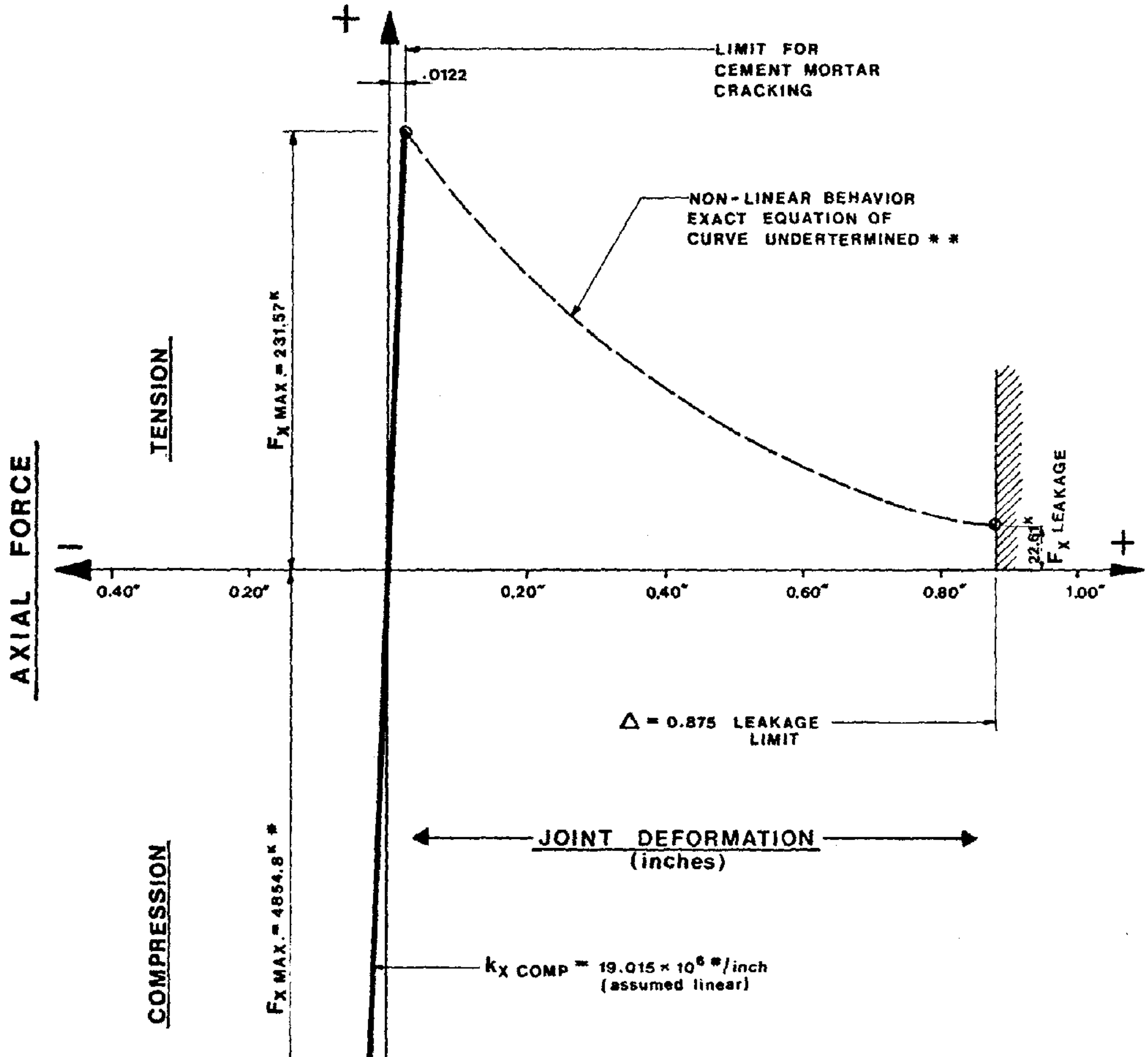


CURVE OF AXIAL FORCE VERSUS EXTENSIONAL DEFORMATION FOR 30" PCEC RUBBER GASKETED PIPE JOINT WORKING PRESSURE - 150 psi

FIG. 10

* OVERALL BUCKLING OF JOINTED PIPE IN A ELASTIC MEDIUM MUST BE CHECKED

** W.A. IN THEIR FUTURE RESEARCH PROPOSAL TO N S F HAS SUGGESTED THAT GROUTED AND UNGROUTED JOINT TESTS BE PERFORMED UNDER VARYING HYDROSTATIC PRESSURES, TO VERIFY THE LIMITS FOR CEMENT MORTAR CRACKING AND LEAKAGE, AND TO ESTABLISH THE CURVE SHAPE EMPIRICALLY.

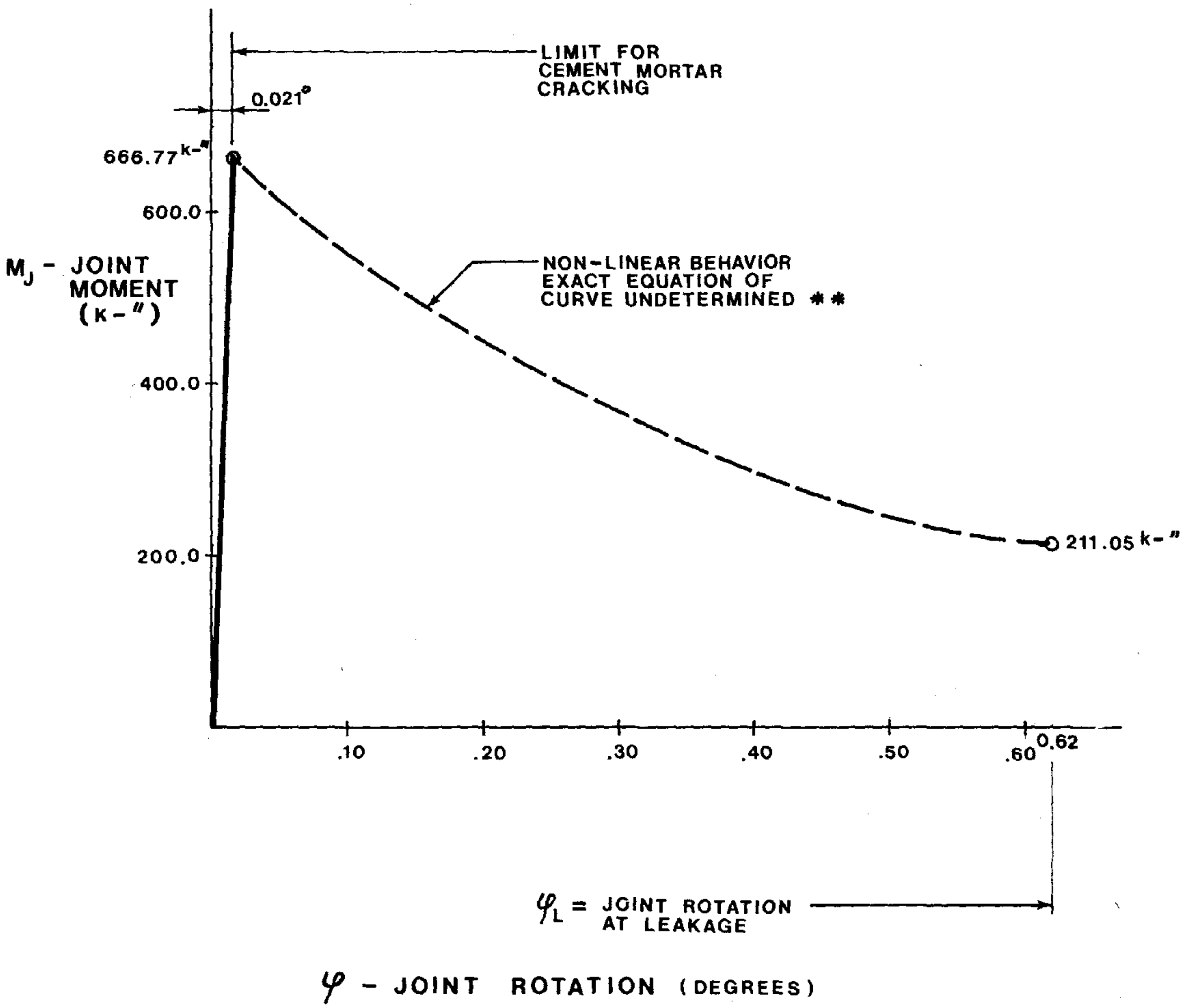


CURVE OF AXIAL FORCE VERSUS EXTENSIONAL DEFORMATION FOR 60" PCEC RUBBER GASKETED PIPE JOINT WORKING PRESSURE - 150 psi

FIG. 11

* OVERALL BUCKLING OF JOINTED PIPE IN A ELASTIC MEDIUM MUST BE CHECKED

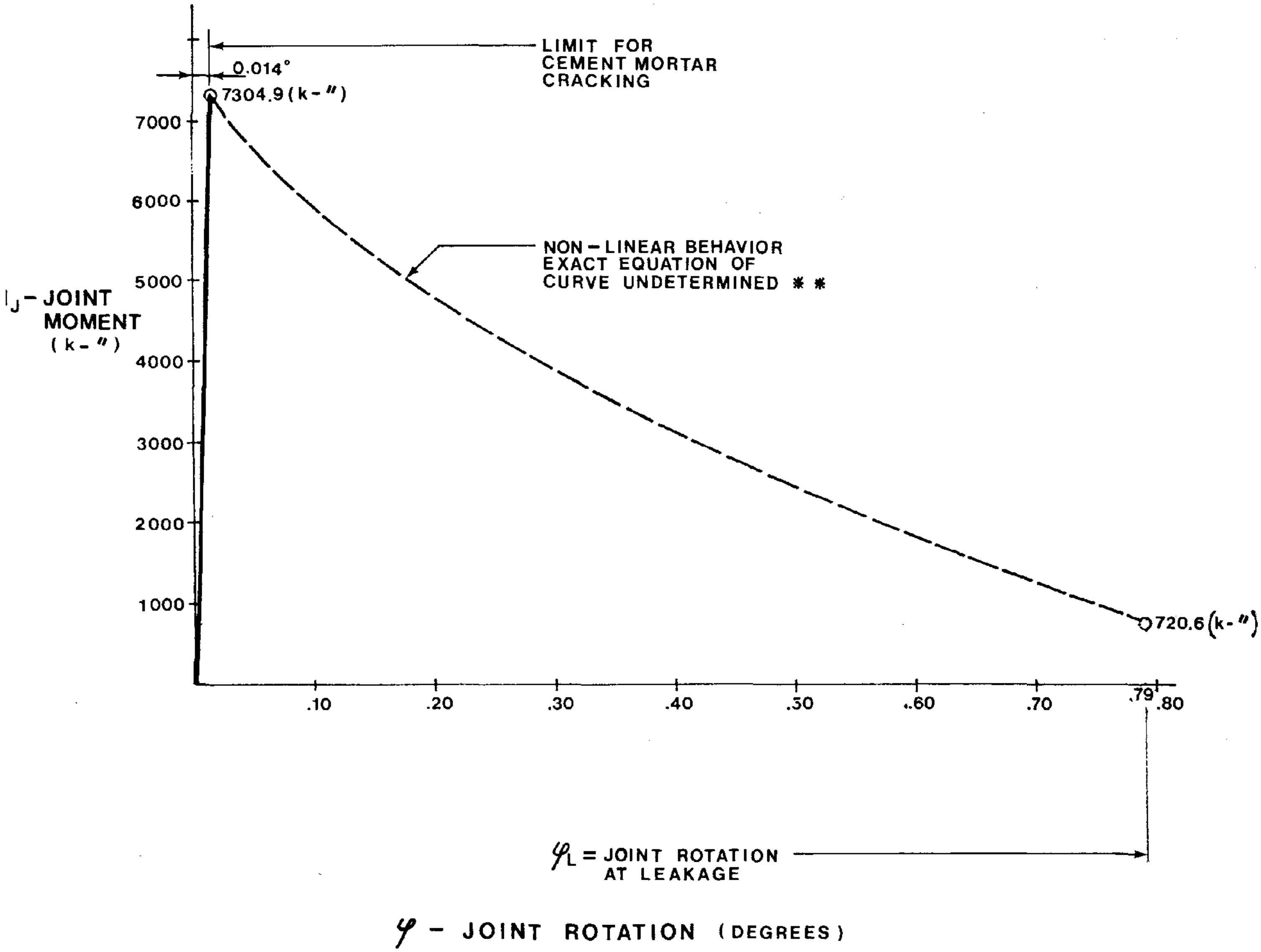
** W.A. IN THEIR FUTURE RESEARCH PROPOSAL TO N S F HAS SUGGESTED THAT GROUTED AND UNGROUTED JOINT TESTS BE PERFORMED UNDER VARYING HYDROSTATIC PRESSURES, TO VERIFY THE LIMITS FOR CEMENT MORTAR CRACKING AND LEAKAGE, AND TO ESTABLISH THE CURVE SHAPE EMPIRICALLY.



JOINT MOMENT ROTATION CURVE FOR 30" PCC RUBBER GASKETED PIPE JOINT WORKING PRESSURE - 150 psi

** W.A. IN THEIR FUTURE RESEARCH PROPOSAL TO N S F HAS SUGGESTED THAT GROUTED AND UNGROUTED JOINT TESTS BE PERFORMED UNDER VARYING HYDROSTATIC PRESSURES, TO VERIFY THE LIMITS FOR CEMENT MORTAR CRACKING AND LEAKAGE, AND TO ESTABLISH THE CURVE SHAPE EMPIRICALLY.

FIG. 12



JOINT MOMENT ROTATION CURVE FOR 60" PCEC RUBBER GASKETED PIPE JOINT WORKING PRESSURE - 150 psi

** W.A. IN THEIR FUTURE RESEARCH PROPOSAL TO N S F HAS SUGGESTED THAT GROUTED AND UNGROUTED JOINT TESTS BE PERFORMED UNDER VARYING HYDROSTATIC PRESSURES, TO VERIFY THE LIMITS FOR CEMENT MORTAR CRACKING AND LEAKAGE, AND TO ESTABLISH THE CURVE SHAPE EMPIRICALLY.

FIG. 13

For the 60" PCEC pipe at a working pressure of 150 psi, with

M_f = 126.5 lbs-sec^2/in.

and M_e = 63.15 lbs-sec^2/in (see Part V,3,p.179)

$$T_{f,g} = 2\pi \sqrt{\frac{126.5}{25.837\text{x}10^3}} = 0.440 \text{ sec.}$$

$$T_{e,g} = 2\pi \sqrt{\frac{63.15}{25.837\text{x}10^3}} = 0.311 \text{ sec.}$$

k) <u>Rotational Periods for the Rubber Gasketed Pipes.</u>

<u>For the 30" PCC pipe</u> at a working pressure of 150 psi:

$$T_{f,g} = 2\pi \sqrt{\frac{I_{\substack{f,g\\e,g}}}{k_{\phi,g}}}$$

With: M_f = 32.66 lbs-sec^2/in (see Part V 3, p.179)

M_e = 16.82 lbs-sec^2/in,

L = length of pipe

D_{max} = O.D. of the pipe

the mass moments of inertia of the full and empty pipe are:

$$I_{\substack{f\\e}} = M_{\substack{f\\e}} \left[\frac{L^2}{3} + \frac{3\,D_{max}^2}{8}\right] = M_{\substack{f\\e}} \left[\frac{(20\text{x}12)^2}{3} \text{ x } 3\, [\frac{30+2(2.6875)}{8}]^2\right] = 19{,}669.3\, M_{\substack{f\\e}}$$

I_f = 32.66 (19,669.3) = 642,398.4 lbs. in. sec.^{2}

I_e = 16.82 (19,669.3) = 330,837.6 lbs. in. sec.^{2}

$$T_{f,g} = 2\pi \sqrt{\frac{642.3984\text{x}10^3}{194.161\text{x}10^5}} = \frac{2\pi}{10} (1.819) = 1.143 \text{ sec.}$$

$$T_{e,g} = 2\pi \sqrt{\frac{330.8376\text{x}10^3}{194.161\text{x}10^5}} = \frac{2\pi}{10} (1.305) = 0.820 \text{ sec.}$$

For the 60" PCEC pipe at a working pressure of 150 psi:

With: M_f = 126.5 lbs-sec^2/in. (see Part V 3, p.179)

M_e = 63.15 lbs-sec^2/in.

$$\frac{L^2}{3} + \frac{3\ D_{max}^{\ 2}}{8} = 19,200^{\ 2} + 3\ [\frac{60 + 2(5.375)]^2}{8}] = 21,077.1\ in^2$$

$$I_f = 126.5\ (21,077.1) = 2,666.251x10^3\ \ lbs.in.sec.^2$$

$$I_e = 63.15\ (21,077.1) = 1,331.018x10^3\ \ lbs.in.sec.^2$$

$$T_{f,g} = 2\pi \sqrt{\frac{2,666.251x10^3}{525.012x10^5}} = \frac{2\pi}{10}\ (2.254) = 1.416\ sec.$$

$$T_{e,g} = 2\pi \sqrt{\frac{1,331.018x10^3}{525.012x10^5}} = \frac{2\pi}{10}\ (1.592) = 1.000\ sec.$$

1) Joint Shear Strength and Leakage Deformation

In our studies, the shear characteristics of the pipe joints have been assumed not to be as critical as the extensional and rotational characteristics. Some joint shear tests performed by industry (see Ref. 5 part V) indicate that joint shear failures are initiated by local crushing or splitting of the core at the bell and spigot rings. However, no comprehensive tests data exists for establishing the characteristics of grouted and ungrouted joints under varying hydrostatic pressures. WA in their new research work proposal to NSF has suggested a test procedure to provide some of the needed data in order to evaluate such joint shear characteristics.

PART VI. ULTIMATE MATERIAL STRENGTH AND DAMAGE MATRICES.

The critical forces or deformations which cause failure of a pipe can be determined independently of each other to show which is dominant in an actual failure or leakage. Although no such forces or deformations actually exist independently in the pipeline, the listing of such forces and deformations in tabular form indicates the relative weaknesses and strengths of a particular kind of pipe. A Damage Matrix lists the pipe and joint forces and deformations which determine the failure and leakage of a given pipe, when only one type of force or deformation acts on it (ignoring the soil-pipe interaction). Such matrices appear in Table II for a 30" diameter PCC pipe and in Table IV for a 60" diameter PCEC pipe. Examples of calculations of Damage Matrices are given hereafter. In preparing these calculations we used Tables I and III, listing the ultimate material strengths and symbols for the PCC and PCEC pipes. Previous standard nomenclature used in Parts I-V, and listed and defined in Part IV, pages 110 and 111, have also been used in computing the ultimate and leakage characteristics of pipes.

A) 30" PCC - Pipe

Longitudinal Compression - P_{uc}:

$$P_{uc} = A_{yT}F_y + A_cF_c' \sqrt{\frac{F_y}{0.0018E_s}} \text{ ;where } F_y/0.00018E_s \leq 1.0$$

(See Ref. 2, p. 546 for ultimate axial load of concrete-filled steel tubular column.)

$$P_{uc} = 6.456\ (41.0) + 2.6875\ (2\pi \times 16.385)\times 6.0 \quad \times \sqrt{\frac{41.0}{0.0018(28000)}} = 1762.1 \text{ kips}$$

Longitudinal Tension - P_{ut}:

For the 30: PCC pipe,

$$f_c' = 6000 \text{ psi},$$

the ultimate concrete tension in the core: $f_{ut} = 12\sqrt{f_c'} = 929.5$ psi

(from ACI 318.71, Chapt. 18 18.4, p. 58)

$$f_{cr} = 1663.0 \text{ psi}$$

$$f_{ut} + f_{cr} = 929.5 + 1663.0 = 2592.5 \text{ psi}$$

Use $\phi = 0.90$ for bending

$\phi = 0.85$ for shear and torsion (from ACI 318.71, Sect. 10.2.7., See Ref. 6)

$$P_{ut} = \phi_t(A_{yT} \cdot F_y + A_c f_t) = \phi_t(A_{yT} F_y + t_w \times 2\pi\bar{R} \times f_{ut})$$

$$= 0.90[6.456\ (41.0) + 2.6875 \times 2\pi(16.385)\ 0.93]$$

$$= 469.8 \text{ kips}$$

Vertical or Horizontal Shear on Cross-Section - V_u:

$$V_u = \phi_s(A_{yT} \cdot \tau_y + A_c f_{ut}) \quad \text{(where } \tau_y = \text{shear yield stress)}$$

$$= 0.85(6.456 \times 19.1 + 2.6875 \times 2\pi(16.385)\ 0.93)$$

$$= 323.5 \text{ kips}$$

Torsional Moment of Cross-Section - T_u:

$$T_u = \phi_s\{2\pi\bar{R}\cdot\bar{R}\ \ t_y \cdot \tau_y + t_w(f_{ut} + f_{cr})\}$$

$$= 0.85\{2\pi\ (16.385)^2[(0.0610 \times 19.1) + (2.6875 \times 2.593)]\}$$

$$= 11{,}662 \text{ in-kips}$$

Ring Compression - C_{ur}:

$$C_{ur} = \phi_c\{A_y \times (F_y - f_{yi}) + 12t_w(f_c' - f_{cr})\}$$

Assuming no internal pressure:

$$f_{yi} = \eta_i f_{ci} = 6(2.135) = 12.81 \text{ ksi}$$

$$C_{ur} = 0.75\{0.7320\ (41.0 - 12.8) + 32.25(6.0 - 1.663)\}$$

$$= 120.4 \text{ kips/ft}$$

Ring Shear - V_{ur}:

$$V_{ur} = \phi_s[A_y\ \tau_y + 12t_w(f_{ut} + f_{cr})]$$

$$= .85[0.7320\ (19.1) + 32.25(2.593)]$$

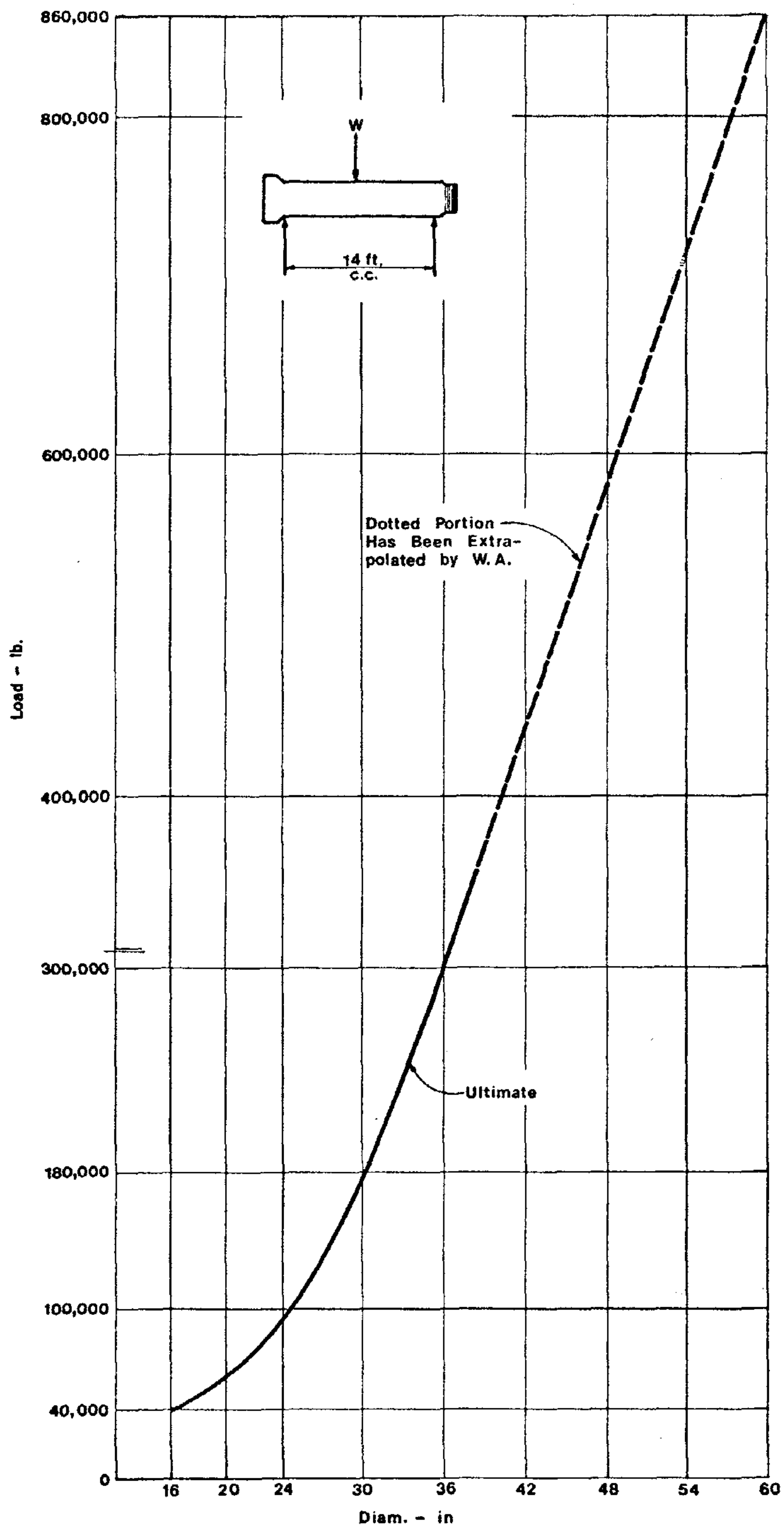
$$= 82.96 \text{ kips/ft}$$

Longitudinal Bending Moment:

Using Fig. 1, from Ref. 39 Part IV , the Ultimate Vertical Load W = 176 kips. Therefore, the ultimate bending moment for the pipe cross-section is

$$M_u = \frac{WL}{4}, \quad \text{where } L = 14 \text{ ft.}$$

$$M_u = \frac{176. \times 14.}{4} = 616 \text{ k-ft} = 7{,}392{,}000 \text{ lb-in.}$$



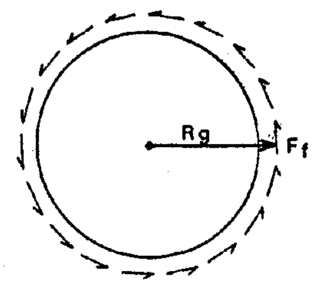
BEAM STRENGTH

From AWWA Journal Nov. 1950 Prestressed Pipe Design by Hugh H. Kennison. See Ref. 39, Part IV

FIG. 1

Rigid Body Twisting Moment, T_j

At a working pressure of 150 psi



SCHEMATIC DIAGRAM OF SHEAR FLOW AT A GASKETED JOINT

FIG. 2

$$R_g = D_g/2, \; F_{f150} = \mu_g w_g \sigma_{gc} = 0.70(0.75)215 = 112.88 \text{ \#/lin. in.}$$

$$T_j = 2\pi \, \overline{R}_g^2 \times F_{f150}$$

$$D_g = 34.50'' \quad R_g = 17.25''$$

$$T_j = 2\pi(17.25)^2 \times 112.88 = 211{,}045 \text{ in-lbs.}$$

Circumferential Bending Moment (at springline)(*)) - M_{ur}:

The distance a_u from the extreme compression fiber of the plastic compression block (shown shaded in Fig. 3) is determined by equating the ultimate compressions to the ultimate tensions. The initial prestressing forces in the wire, and the core and cylinder initial precompression forces are in equilibrium, and hence only the differences between the precompression and prestressing forces and the ultimate strength forces can be used in determining the ultimate bending moment of the ring section.

$$0.85(f_c' - f_{ci}) \, 12a_u + A_c f_{ci} + A_y f_{yi} = (f_{mur} + f_{si})A_s + f_{yb} \, A_y, \qquad \text{(a)}$$

where f_{mur} = the differential ultimate stress in the wire, after the initial prestressing (ksi)

(*) It is assumed that the maximum M_{ur} moment has the greatest probability of occurring at the springline.

See p. 110-111, Part IV for a definition of the other terms.

For strain compatibility, the differential strain in the prestressing wire at the ultimate moment (see Fig. 3) is:

$$\varepsilon_{us} = f_{mur}/28000 \qquad \text{(b)}$$

From the differential strain compatibility diagram shown in Fig. 3:

$$\frac{c}{1.875} = \frac{.003}{.003 + \varepsilon_{us}} ;$$

$$a_u = \beta_1 c \qquad \text{(c)}$$

where $\beta_1 = 0.75$ (See ACI 318-71, Sect. 10.2.7, Ref. 6 of Part VI)

$$\therefore \quad c = 1.33\ a_u \qquad \text{(d)}$$

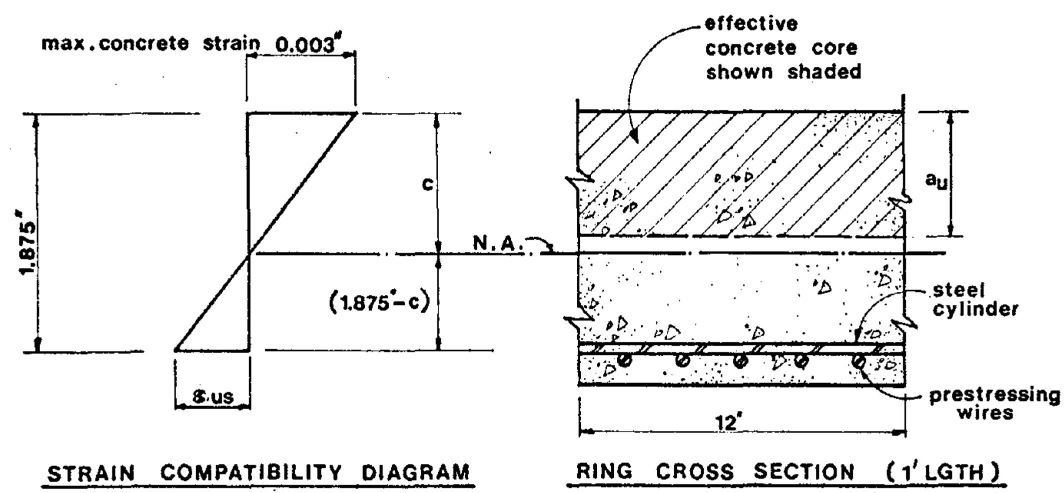


Fig. 3

From (a), (b), (c), (d):

$$a_u = 0.927 \text{ in.}$$

$$f_{mur} = \frac{157.5}{1.33(0.927)} - 84.0 = 43.49, \text{ ksi}$$

which satisfies the condition:

$$f_{mur} + f_{si} \leq 293.0 \text{ ksi, for } f_{si} = 195.5$$

(See Table X, p.113 , Part IV).

Hence:

$$M_{ur} = \phi_b \times T_u \times [a_u/2 + (1.875 - a_u)]$$

where $T_u = f_{mur} \times A_s = 43.49 \quad \times 0.285 \quad = 12.395$ kips

$$M_{ur} = 0.90 \times 12.395 \left[\frac{0.927}{2} + (1.875 - 0.927)\right]$$

$$= 15.746 \text{ k-in/ft} = 15{,}746 \text{ lb-in/ft}$$

TABLE I - PCC PIPE

ULTIMATE MATERIAL STRENGTHS			
COMPONENT	**TYPE OF ULTIMATE STRESS**	**ULTIMATE STRENGTH**	**UNITS**
CONCRETE CORE	COMPRESSION - f_c'	6.0	ksi
	SHEAR OR DIAGONAL TENSION - f_t	930	psi
SPIGOT RING	TENSION - f_{uts}	50.0	ksi
BELL RING	TENSION - f_{utb}	52.0	ksi
STEEL CYLINDER	BENDING - f_{yb}	33.0*	ksi
	TENSION - f_{yt}	41.0	ksi
	SHEAR - τ_y	19.1	ksi
CEMENT MORTAR IN GROUTED JOINT	TENSION - f_{tm}	300	psi

*YIELD STRENGTH

TABLE II - DAMAGE MATRIX

PCC PIPE - 30" DIAM. × 1 7/8" CORE

PIPE CHARACTERISTICS			
TYPE OF PIPE STRESS	TYPE OF ULTIMATE FORCE	ULTIMATE FORCE	UNITS
CIRCUMFERENTIAL	RING COMPRESSION - C_{ur}	120,400	lbs./ft
	RING BENDING - M_{ur}	15,746	in-lbs/ft
	RING SHEAR - V_{ur}	82,960	lbs/ft.
	RING BURSTING* - P_b	560.6	psi
EXTENSIONAL	LONGITUDINAL COMPRESSION - P_{uc}	1,762,100	lbs.
	LONGITUDINAL TENSION - P_{ut}	469,800	lbs.
TRANSLATIONAL	LONGITUDINAL BENDING MOMENT - M_u	7,392,000	in -lbs.
	VERTICAL OR HORIZONTAL SHEAR - V_u	323,500	lbs.
TORSIONAL	TWISTING MOMENT - T_u	11,662,000	in-lbs.

*DENOTES AN INTERNAL PRESSURE DUE TO HYDROSTATIC FORCES

JOINT CHARACTERISTICS 21/32" ϕ RUBBER GASKET, P_W = 150 psi, 20' SEGMENT			
TYPE OF DEFORMATION	TYPE OF LEAKAGE FORCE OR DISPLACEMENT	LEAKAGE FORCE	UNITS
EXTENSIONAL	LONGITUDINAL TENSION - P_{jt}	12,235	lbs.
	LONGITUDINAL COMPRESSION - P_{jc}	1,281,500	lbs.
	MAX. LONGITUDINAL EXTENSION - E	0.375	in.
ROTATIONAL	RIGID BODY ROTATIONAL MOMENT - M_j	211,045	in-lbs.
	RIGID BODY ROTATION - θ_j	0.62	degrees
TORSIONAL	RIGID BODY TWISTING MOMENT - T_j	211,045	in-lbs.
	RIGID BODY TWIST -.225- - ϕ_j	———	degrees

B) <u>60" PCEC Pipe:</u>

<u>Longitudinal Compression - P_{uc}:</u>

$$P_{uc} = 532.1 + 5.375(2\pi \times 32.623)(5.0) \sqrt{\frac{45.0}{0.0018(28,000)}}$$

$$= 5,737.37 \text{ kips}$$

<u>Longitudinal Tension - P_{ut}:</u>

For a 60" PCEC pipe $f_c{}' = 5000$ psi,

$$f_{ut} = 12 \sqrt{f_c{}'} = 848.5 \text{ psi}$$

$$f_{cr} = 1419 \text{ psi}$$

$$f_{ut} + f_{cr} = 848.5 + 1419 = 2267.5 \text{ psi}$$

$$P_{ut} = 0.90[11.824(45.0) + 5.375 \times 2\pi(32.623)(0.849) = 1320.7 \text{ kips}$$

<u>Vertical or Horizontal Shear on Cross-Section - V_u:</u>

$$V_u = 0.85\{11,824 \times 19.1 + 5.375 \times 2\pi(32.623)(0.849)\}$$

$$= 987.1 \text{ kips}$$

<u>Torsional Moment of Cross-Section - T_u:</u>

$$T_u = 0.85\{2\pi(32.623)^2[0.0598(19.1) + 5.375(2.268)]\}$$

$$= 75,783.5 \text{ in-kips}$$

Ring Compression - C_{ur}:

$$f_{yi} = n_i \ f_{ci} = 5(1.788) = 8.940 \text{ ksi}$$

$$C_{ur} = 0.75 \{ 0.7176(45.0 - 12.516) + 12(5.375)(5.0 - 1.419)\}$$

$$= 190.7 \text{ kips/ft}$$

Ring Shear - V_{ur}:

$$V_{ur} = 0.85 [0.7176(19.1) + 64.5(2.268)]$$

$$= 135.993 \text{ kips/ft}$$

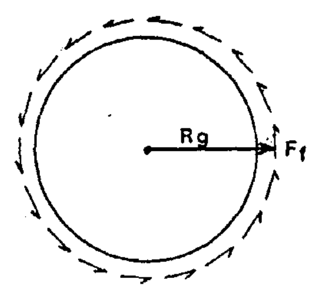
Longitudinal Bending Moment M_u:

Using Fig. 1, from Ref. 39, part IV, the Ultimate Vertical Load W = 860 kips

Therefore: $M_u = \frac{WL}{4}$, where L = 14 ft.

$$M_u = \frac{860 \times 14}{4} = 3010.^{k-ft} = 36,120,000 \text{ lb-in.}$$

Rigid Body Twisting Moment - T_j:



SCHEMATIC DIAGRAM OF SHEAR FLOW AT A GASKETED JOINT

FIG. 4

$$D_g = 63.375'', R_g = 31.875''$$

and $$T_j = 2\pi(31.875)^2 \times 112.88 = 720,605 \text{ in-lbs}$$

Circumferential Bending - M_{ur}:

From the differential strain compatibility diagram shown in Fig. 5, the equilibrium Eq. (a'):

$$0.85(f_c' - f_{ci})12a_u + A_c f_{ci} + A_y f_{yi} + \varepsilon_{yc} E_s A_y = (f_{mur} + f_{si}) A_s \qquad (a')$$

and from (b), (c), on p. 222

$$\frac{c}{4.58} = \frac{.003}{.003 + \varepsilon_{us}} :$$

$$f_{mur} = \frac{384.72}{c} - 84.0; \; a_u = \beta_1 C$$

where $\beta_1 = 0.80$

and from the condition:

$$f_{mur} + f_{si} \leq 293.0;$$

$f_{mur_{max}} \leq 293.0 - f_{si}$ (for f_{si} see p.142 , Part IV)

$\leq 293.0 - 185.35 = 107.65$ ksi

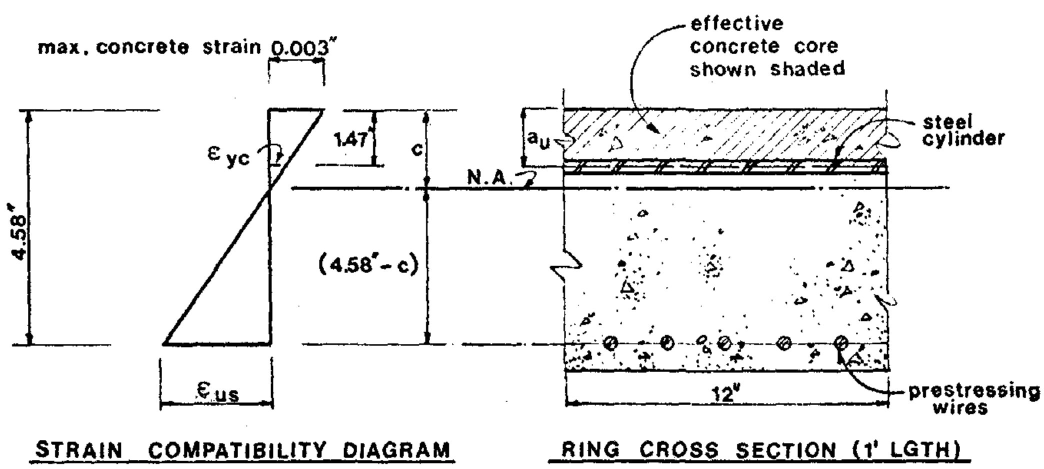


Fig. 5

From (a'), (b), (c) on page 222:

$$a_u = 1.47 \text{ in.}$$

$$c = 1.25\ a_u = 1.25(1.47) = 1.84 \text{ in.}$$

$$f_{mur} = \frac{384.72}{c} - 84.0 = 125.37 > f_{mur_{max}}$$

Hence $f_{mur_{max}}$ must be used, giving:

$$a_u = 1.95 \text{ in.}$$

and $M_{ur} = \phi_b\{A_s f_{mur}(4.58-c)+[84.0(\frac{c-1.47}{c})]\ A_y(c-1.47)+0.85(f_c-f_{ci})12a_u x[\frac{a_u}{2}+(c-a_u)]\}$

$$M_{ur} = 0.90[60.13(4.58 - 1.84) + 16.89(0.7176)(1.84 - 1.47) + 32.89(1-47)(\frac{1.47}{2}$$

$$= 200.394\ ^{k-in/ft} = 200{,}394 \text{ lb-in/ft.}$$

TABLE III - PCEC PIPE

ULTIMATE MATERIAL STRENGTHS			
COMPONENT	**TYPE OF ULTIMATE STRESS**	**ULTIMATE STRENGTH**	**UNITS**
CONCRETE CORE	COMPRESSION - f_c'	5.0	ksi
	SHEAR OR DIAGONAL TENSION - f_t	849	psi
SPIGOT RING	TENSION - f_{uts}	50.0	ksi
BELL RING	TENSION - f_{utb}	52.0	ksi
STEEL CYLINDER	BENDING - f_{yb}	33.0*	ksi
	TENSION - f_{yt}	45.0	ksi
	SHEAR - τ_y	19.1	ksi
CEMENT MORTAR IN GROUTED JOINT	TENSION - f_{tm}	300	psi

*YIELD STRENGTH

TABLE IV - DAMAGE MATRIX

PCEC PIPE - 60" DIAM. × 4½" CORE

PIPE CHARACTERISTICS

TYPE OF PIPE STRESS	TYPE OF ULTIMATE FORCE	ULTIMATE FORCE	UNITS
CIRCUMFERENTIAL	RING COMPRESSION - C_{ur}	190,700	lbs./ft
	RING BENDING - M_{ur}	200,394	in-lbs/ft
	RING SHEAR - V_{ur}	135,993	lbs/ft.
	RING BURSTING* - P_b	518.4	psi
EXTENSIONAL	LONGITUDINAL COMPRESSION - P_{uc}	5,737,370	lbs.
	LONGITUDINAL TENSION - P_{ut}	1,320,700	lbs.
TRANSLATIONAL	LONGITUDINAL BENDING MOMENT - M_u	36,120,000	in-lbs.
	VERTICAL OR HORIZONTAL SHEAR - V_u	987,100	lbs.
TORSIONAL	TWISTING MOMENT - T_u	75,783,500	in-lbs.

*DENOTES AN INTERNAL PRESSURE DUE TO HYDROSTATIC FORCES

JOINT CHARACTERISTICS

21/32" ϕ RUBBER GASKET P_W = 150 psi 20' SEGMENT

TYPE OF DEFORMATION	TYPE OF LEAKAGE FORCE OR DISPLACEMENT	LEAKAGE FORCE	UNITS
EXTENSIONAL	LONGITUDINAL TENSION - P_{jt}	22,607	lbs.
	LONGITUDINAL COMPRESSION - P_{jc}	4,854,800	lbs.
	MAX. LONGITUDINAL EXTENSION - E	0.875	in.
ROTATIONAL	RIGID BODY ROTATIONAL MOMENT - M_j	720,605	in-lbs.
	RIGID BODY ROTATION - θ_j	0.79	degrees
TORSIONAL	RIGID BODY TWISTING MOMENT - T_j	720,605	in-lbs.
	RIGID BODY TWIST - ϕ_j	———	degrees

PART VII

State of the Art

The RC, RCC, RCCP, PCC and PCEC types of concrete pipe for underground pipelines are currently designed for hoop and bending stresses and for control of ring ovalizing and cracking due to superimposed loads. The well-known work of Marston and Spangler at the Engineering Experiment Station at Iowa State College (see ref. 1 & 2) provided the industry with the needed design procedures for concrete pipes with rigid and semi-rigid contact pressures distributions, and have been proven to be reliable in providing conservative designs for pipes under normal loading conditions of hydrostatic pressure and earth and traffic loads. However, in the light of current technology, and because of the need for more realistic pipe models in connection with shock and seismic loading, a more comprehensive unified and refined approach is needed. Current procedures depend on a variety of "lumped" parameters rather than on the fundamental properties of the soil-structure system. Examples of such parameters are the modulus of soil reaction, which is obtained from tests, and the settlement ratio, which groups together the relative compressibilities of the individual components of the system. The determination of the values for both these parameters involves substantial engineering judgements. The presently accepted procedures classifies the external pipe pressure distributions according to three distinct arbitrary categories of pipe rigidity arrived at empirically, and does not formulate a continuum theory to relate the external pressure distribution to the actual soil-structure interaction. While a continuum approach would be more representative of actual field conditions, its mathematical complexities are not generally tractable in closed form and

recourse must be made for their solution to numerical methods usually by means of finite elements. In 1966, Drowsky outlined such an approach (see ref. 3) and in 1967, Brown started to develop finite element programs for both flexible and rigid culvert under high fills (see ref. 4).

The development of such numerical procedures, especially the finite element approach, offers considerable promise for the improvement of buried pipe analysis and design, as these methods can take in account pipe and joint stiffnesses, non-linearities in the stress-strain diagrams of the materials, nonhomogeneous soil conditions, non-linear soil behavior, non-linear contact interfaces and time dependent incremental loadings.

Once a concrete pipe section has been selected for a given bedding and soil environment, two or three dimensional finite element analysis can be used to evaluate the stresses and strains in the pipe when it interacts with a modelled soil environment consisting of a combination of static and/or dynamic forces.* Finite element solutions may be based on linear or non-linear behavior and incorporate either small or large deformation theory (see ref. 5-14).

The linear small deformation theory may be modified to take into account slippage at the soil-pipe interface and boundary separations in the modelled soil environment. (See ref. 14). The presence of initial stresses in the pipe-soil interaction model, due to pipe manufacture and installation or change in soil pore pressures after installation, may also be taken into account.

*For small pipe diameters handling and installation may govern the design.

The solutions obtained so far by elasticity theory, that were useful in establishing the basic concepts involved in the analysis, do not provide as comprehensive a tool as the more versatile finite element method. However, with greater refinement and more accurate modelling, the cost of the analyses increases. The limiting contraints of the problem are the solution costs and the ability to simulate the real environmental conditions. It has now become economically feasible to provide packaged computer programs that will analyze common buried concrete pipes for the normal types of loading, (except seismic or shock loads) in a two-dimensional ring analysis which considers stresses and deformation in the plane of the pipe ring only. Recently Katona (see ref. 15) developed the CANDE Computer Program for the Design of Reinforced Concrete Culverts, which performs a 2-D ring analysis by elasticity or finite element methods for culvert pipes in a defined linear or non-linear soil environment. The CANDE program assumes a material with a trilinear stress-strain curve, which approximates the elastic, initial yielding, and crushing phases of concrete behavior. An idealized linear stress-strain model is used for the reinforcing steel. Parmelee and Wenzel under contract to the American Concrete Pipe Association have developed recently a two-dimensional finite element program entitled NUPIPE (see ref.16) which models half of the symmetrical pipe ring for a reinforced concrete pipe (type RC only) in a defined soil environment. The NUPIPE program utilizes an iterative technique to insure deformation compatibility in the soil-pipe model within the plane of pipe ring (normal to the longitudinal axis of the pipe).

The finite element used is a quadrilateral that can have non-linear material properties. For the concrete,the non-linear stress-strain relationship proposed by Hognestad (see ref. 17) has been used. The selection of a finer finite element mesh in the critical tensile areas of the ring gives exceptionaly good correlation between the computer model and full scale load tests. Fig. 7A(1) (from ref. 16) shows a simplified version of the typical finite element grid for the soil-pipe model with the layered elements through the pipe wall not shown. A more complete detailed representation for the finite element layered mesh of the modelled pipe wall (for a 3 edge bearing test) is also shown in Fig. 7A(2). (from ref. 18).

At the time of this writing, the NUPIPE Program and its Design Manual have not been released for general use by the American Concrete Pipe Association (ACPA) as it is in the process of being tested and correlated with actual field installations.

An example of linear three-dimensional finite element analysis for a steel pipe-soil system has been given by Allgood and Takahashi of the U.S. Naval Civil Engineering Laboratories (see ref. 19). Allgood and Takahashi have analyzed a steel culvert pipe in a soil embankment by modelling a quadrant of the pipe-soil system (see Fig. 7A(3) from ref. 19). The culvert pipe was assumed to be empty and the effect of traffic load insignificant in view of the depth of fill. The results of this culvert analysis are reproduced in Fig. 7B(1-4)&7C (from ref. 19). Although this analysis considers only a static

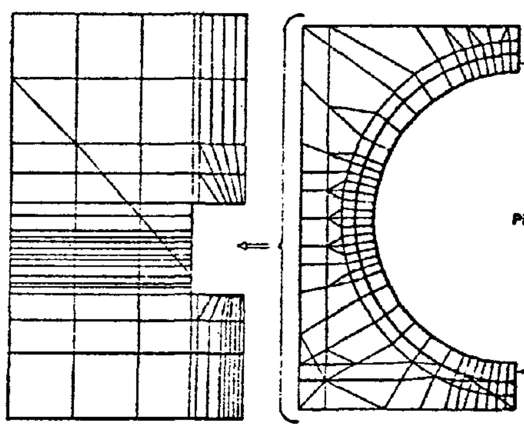


Fig. 7A (1) Mixed-element pipe model incorporated into a field grid.

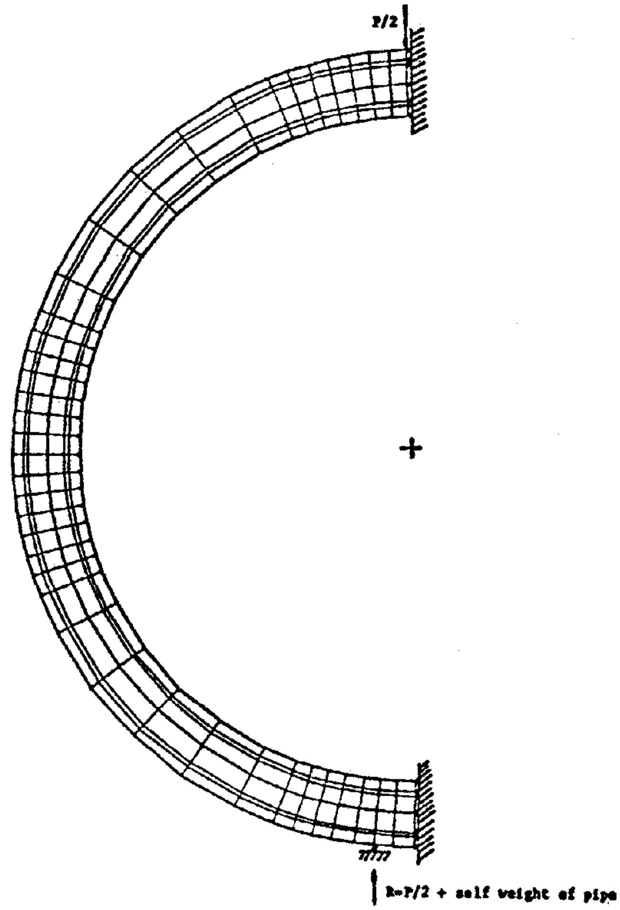


Fig. 7A (2) Mixed-element representation of 3-edge bearing test.

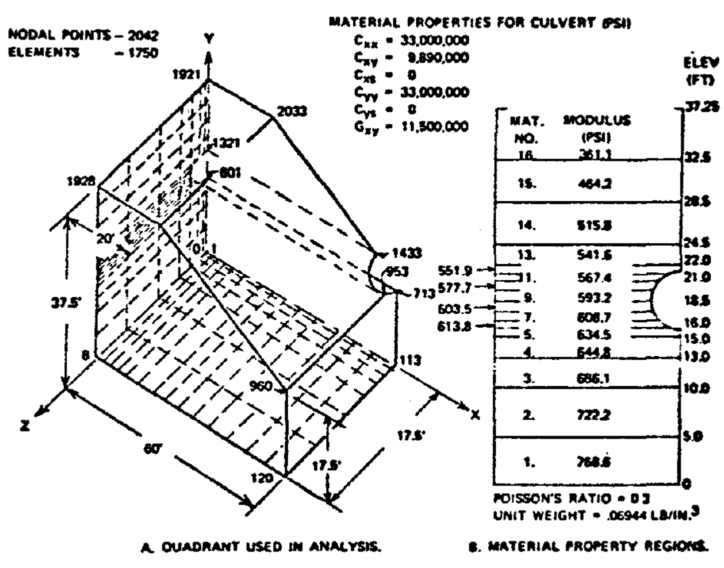


Fig. 7A (3) Soil-culvert system model.

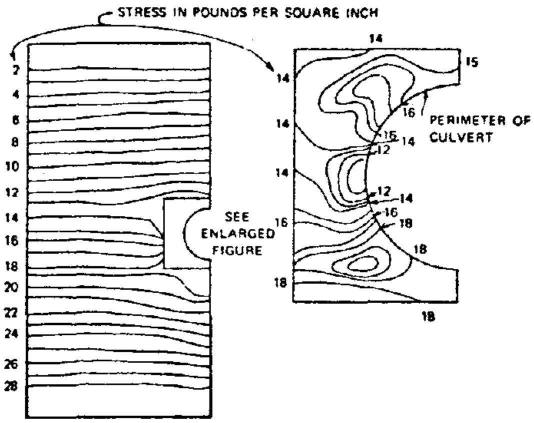


Fig. 7B(1) Vertical soil stress contours
(Y-Z plane)

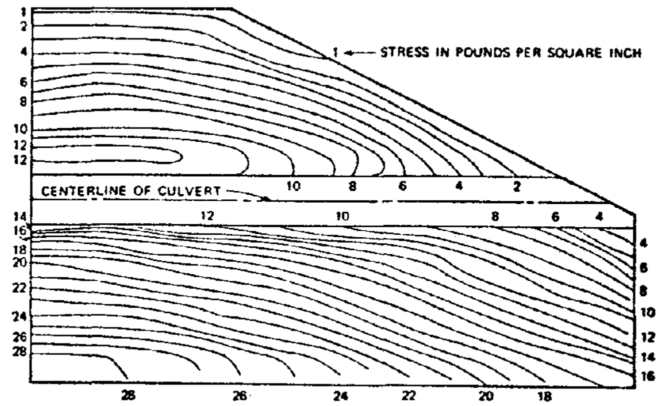


Fig. 7B(2) Vertical soil stress contours
(X-Y plane)

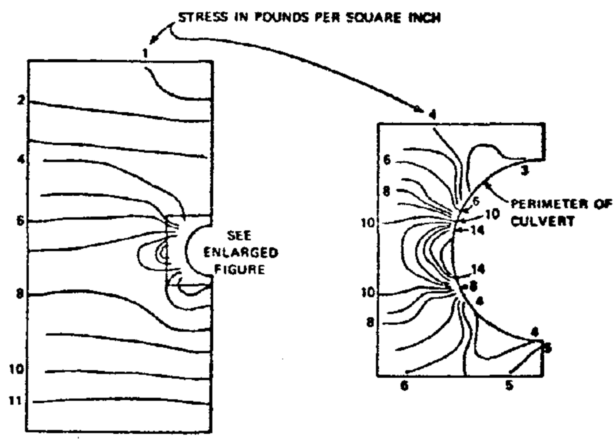


Fig. 7B (3) Horizontal soil stress contours
(Y-Z plane)

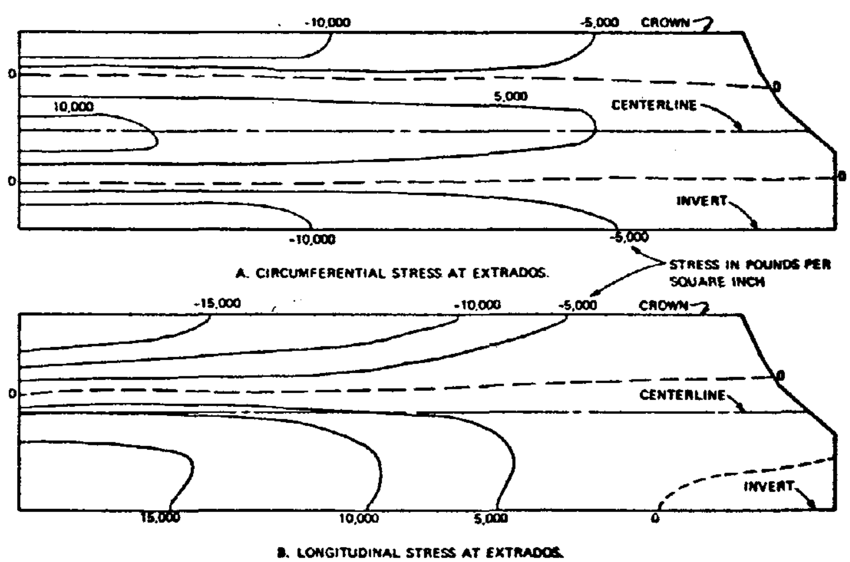
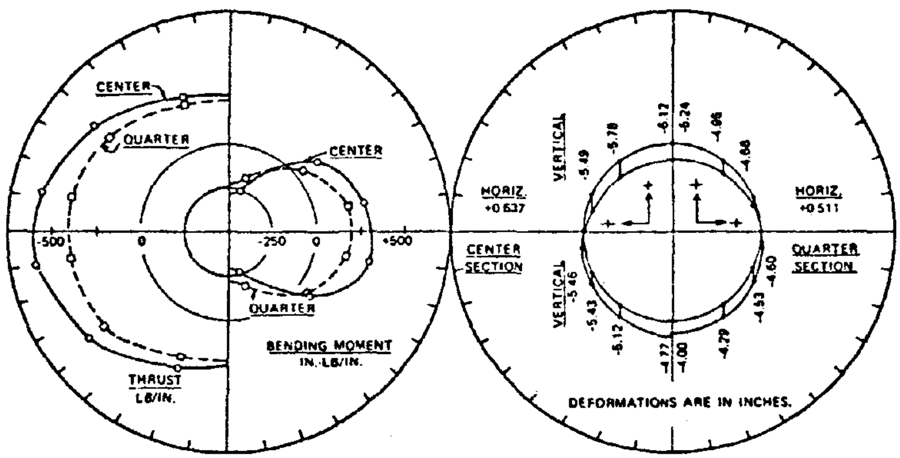


Fig. 7B (4) Stress contours on developed longitudinal half-section.



A. THRUST AND BENDING MOMENT.

B. HORIZONTAL AND VERTICAL DEFORMATIONS.

Fig. 7C Forces and deflections on transverse section.

earth load and one segment of steel pipe, it exemplifies the complexity of the problem when dealing with both longitudinal and circumferential stresses.

Parmelee has also presented a new design computer method, called NUDESIGN for the analysis of the pipe ring stresses by means of a mini computer or programmable pocket calculator (see ref. 20). In the NUDESIGN procedure the maximum stress resultants at the invert and springline of the pipe are calculated by means of eight non-dimensional coefficients, which were generated from the more comprehensive NUPIPE program and take into account the soil-pipe interaction for the standard types of bedding conditions. At present the documentation and design manual for NUDESIGN is not available from the ACPA.

The present state of the art offers no comprehensive computer programs or generally accepted three-dimensional design methods for the analysis and design of buried water pipes under normal loadings, taking into account soil-structure interaction, actual material properties and methods of construction (especially at the joints).

Many general purpose shell programs, such as BOSAR, NASTRAN, DANUTA, SAP and STAGS are useful in analyzing the shell walls without soil interaction. However, their use requires a great deal of engineering judgement and effort in order to establish proper boundary conditions and meshes to represent the real buried pipe.

One of the important aspects of any pipe modelling is the proper representation of the joint characteristics. Unfortunately, very meager test information exists about the actual behavior of the gasketed bell-and-spigot type of joint (as installed in the field). "Joint Pull Tests" only measure the forces required to make-up joints with lubricated gaskets and no hydrostatic pressure. No information is available on pulling joints apart after the gasket lubricant has dried, the joint has been grouted with cement and is under a normal hydrostatic pressure. The actual behavior of the confined gaskets in the PCC and PCEC pipes under pressure, subjected to either longitudinal, transverse, torsional or rotational forces, is quite complex. Some manufacturers have indicated to W.A. that they have recently conducted tests on joint behavior, but that they are in the process of correlating the corresponding data and are not ready to release the results at the present time.

Considerable search for material on joint behavior indicates that very limited technical information on the subject is available in the form of published articles or technical reports, because this work is of a proprietary nature and entails considerable time and effort on the part of the manufacturers.

W.A., therefore, conclude that tests supported by Federal funds and conducted by independent university or other laboratories are seriously needed.

PART VIII

Conclusions and Recommendations:

The design examples shown in this report are based in general on industry's conservative approach for normal loadings and represent the design methods used today by the major manufacturers. In investigating more in depth these procedures, W.A. has become aware of short comings, questionable design assumptions, and the limited applicability of these methods to concrete pipeline design for dynamic seismic forces, as they do not reflect to-day's more sophisticated dynamic technologies. These limitations have been discussed at length in Part VII. The ultimate interaction curves for the PCC and PCEC pipes in Part V of this report are only useful in establishing the order of magnitude of the ultimate superimposed vertical loads for serviceability (leakage), when the ring forces control the design. The actual ultimate capacity of a pipe ring section may be significantly different from that given by the interaction curves, when the pipe may be subjected to two-or-three-dimensional differential displacements in addition to the normal ring forces. As shown in Part V, bedding and construction installation conditions can radically effect the factor of safety and reserve of strength for vertical loads. Hence, the selection of an ambient pipeline environment, may be an important parameter in determing the dynamic energy absorbing capacity or ultimate strength of the pipe prior to leakage or failure. The best approach for establishing design criteria for pipelines subject to complex seismic loading conditions can only be addressed after the general nature of these dynamic forces is understood and can be quantized. W.A. is investigating this problem at the present time and has established in this and prior reports a methodology for the assessement of the main parameters reflecting the pipe and joint properties of importance in a dynamic study. (For a more comprehensive discussion of the concepts and parameters involved, see IR-1, IR-2 and the Future Work proposed by W.A. to N.S.F.). On the basis of the conclusions above the following recomendations are made by W.A. concerning the need of additional work to complete the results obtained in IR-3, IR-3a and IR-5:

(a) In view of the common usage of mild steel and cement asbestos in underground pipelines, it is advisable to derive ultimate strength and damage matrices for pipelines made out of these materials, taking into account the types of joints typical of such lines.

(b) In order to be able to perform seismic analysis on general pipelines it is essential to derive ultimate strength and damage matrices for pipelines whose segments are not jointed in-line.

(c) In order to fill the gaps in the present knowledge of pipeline design it is of practical value to compile a summary of the more advanced design methods being considered by researchers at the present time, which may influence the standard design procedures adopted in the future by the major manufacturers.

For a more comprehensive discusion of these recommendations see the Future Work Proposal of W.A. to N.S.F.

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