Field Performance of Cast-in-Place Nonreinforced Concrete Pipe

CURTISS W. GILLEY AND L. H. GABRIEL

A compilation of case histories of cast-in-place nonreinforced concrete pipe (a continuous monolithic cast underground conduit for irrigation water, storm water, sewage, and industrial waste) is presented. The results of field tests corroborate the value of passive restraint at the springline. Eight field studies dating back to 1954 demonstrate the load-carrying and hydrostatic capabilities of cast-in-place concrete pipe.

The case studies of nonreinforced cast-in-place concrete pipe (CIPCP) presented encompass a period of more than 38 years of in-service field experience.

By American Concrete Institute (ACI) Specification 346 definition, "CIPCP is an underground continuous nonreinforced concrete conduit, having no joints or seams, except as necessitated by construction requirements. It is intended for use to convey irrigation water, storm water, sewage, or industrial waste under a maximum internal operating head of 45 kPa (15 ft.) and external loads . . ." (*1*).

HISTORY OF CIPCP

Although a process for cast-in-place concrete pipe was first patented in 1897, it was not until the early 1920s that the Turlock Irrigation District in California's San Joaquin Valley pioneered its commercial use. Unlike today's machine monolithic casting process, these early pipes were hand (and later, machine) cast in two semicircular segments. Undesirable cold joints appeared at springline where the two segments joined.

The first modern casting machines was used in 1949. Because the function of these pipes in that year was for irrigation water, sizes were limited to 1220 mm (48 in.) in diameter. Application to storm sewer pipelines quickly followed in the early 1950s. Today, sizes with diameters of 610 mm (24 in.) through 3048 mm (120 in.) are routinely constructed. Approximately 3500 km (2,200 mi) of CIPCP has been installed to date, with approximately 22 percent with diameters of 1372 mm (54 in.) or larger. Most of the installations are located in California, Arizona, Texas, New Mexico, Oregon, and Washington. CIPCP has also been installed in Mexico City, Mexico, and Johannesburg, South Africa.

STRUCTURAL PERFORMANCE OF CONCRETE PIPE

The dominating characteristic of a brittle material, such as concrete, is a low threshold of tensile capability. For the reliable performance of concrete pipe, either the internal tensile forces must be transferred, through bond, to tough, ductile, steel reinforcing bars of large tensile capacity or the internal tensile forces must be significantly reduced by developing a compensating force field. Precast reinforced concrete pipe (RCP) is an example of the former; nonreinforced CIPCP is an example of the latter.

When responding to the application of loads, the pipe wall internal reacting forces of shear, in-plane thrust (wall thrust), and bending moment (wall bending) all contribute to the composite stress response. For rigid structures, such as concrete pipe, secondary stress effects due to deflections are assumed negligible; the deformed structure lies well within the bounds of small deflection theory.

The in-plane circumferential stress of wall thrust may be added arithmetically to the flexural stress of wall bending because both forces result in parallel stress fields that track the wall circumference. A properly designed and constructed CIPCP will enjoy an increase in the favorable wall thrust and a decrease in the unfavorable wall bending so as to mask, or nearly mask, the wall-bending tensile stress to which concrete is vulnerable. This is accomplished by the self-induction of passive lateral forces in the vicinity of springline when the lengthening horizontal diameter (under increasing load) engages the stiff walls of the trench which previously served as forms for the casting of the pipe. This is not unlike the way an arch structure develops lateral reaction forces at the supports, which serves to increase internal thrust and decrease internal bending. RCP, which does not enjoy the full benefits of the compensating effects of lateral support at springline, utilizes reinforcement to engage the high tensile stresses that result from wall bending.

CONSTRUCTION PROCEDURES

The first step in the construction process is to excavate a trench with vertical side walls and a round bottom, shaped with a round bottom bucket attached to a tracked excavator or backhoe. [For further information, see the Lynch Manual (*2*) pipe and trench detail, Figure 1, and Table 1.] Alignment is laser controlled.

The pipe casting machine (Figure 2) is placed in the trench, and its motor-driven winch system (Figure 3) is secured to an installed trench anchor. At the start of the process, and continuing in pace with the advancing casting machine, loose metal top forms shaping and containing the upper 270 degrees are positioned to receive concrete. Through a hopper that is integral with the casting machine, a low-slump 25- to 76-mm

C. W. Gilley, Tremont Equipment Co., Inc., 6940 Tremont Road, Dixon, Calif. 95620-9603. L. H. Gabriel, School of Engineering, California State University, 6000 J Street, Sacramento, Calif. 98519-2694.

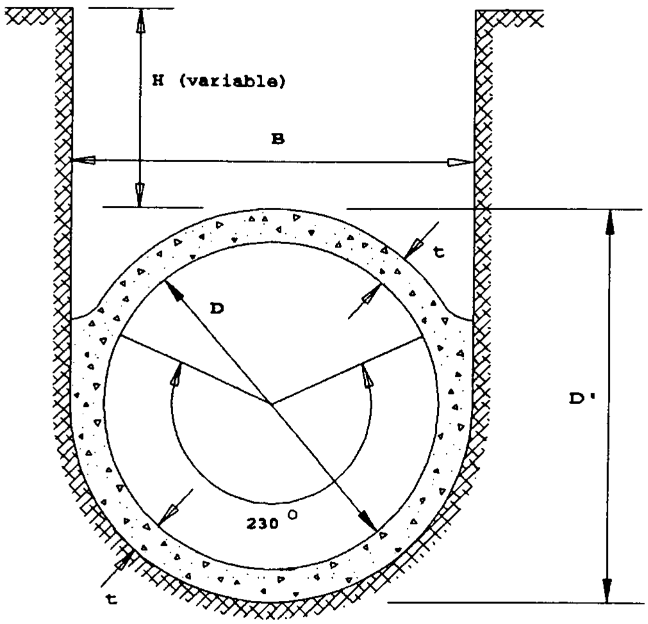

FIGURE 1 Typical cross section of cast-in-place concrete pipe [610–3048 mm (24–120 in.)].

(1- to 3-in.) concrete of modest strength with a minimum 28-day strength of 20.7 MPa (3,000 psi) is placed, tamped, and vibrated to achieve full consolidation. A polyethylene blanket is often used for accelerated curing. Under typical conditions, the production rate ranges from 30 m (100 ft) to 7 m (23 ft) per hour depending on the size, 610-mm diameter to 3048-mm diameter, of the pipe.

After 6 hr, the top forms may be removed. When the concrete achieves a strength of 17.2 MPa (2,500 psi), usually in 2 to 3 days, trench backfilling may begin. Circumferential shrinkage cracks, which are best understood to be joints in the continuously cast pipe, will appear every 7.6 m (25 ft) to 15.2 m (50 ft), or more, depending on curing conditions, the quality of the concrete, and trench moisture conditions. The cracks have no structural significance and need only to be grouted to prevent infiltration, if such is a consideration.

DESIGN CONSIDERATIONS

The following ACI (*1*) engineering design procedure yields a statement of the stress in the pipe wall.

Marston earth loads for the trench conditions are used to define vertical dead loads. Appropriate AASHTO highway loads, FAA aircraft loads, and Cooper rail loads define the live loads. Compensating lateral loads (see section on Structural Performance of Concrete Pipe) are taken conservatively as Rankine active pressures, a significant underestimate of the passive pressures known to be working when the stiff lateral walls are engaged by the pipe. The pipe dead load, the weight of the water in the pipe, and hydrostatic heads may be included as required.

Moments and thrusts may be computed using coefficients developed by Paris (*3*) or Roark compiled by Young (*4*). Stresses at critical points of tension (at crown, invert, and springline) are calculated in appropriate units from the following interaction formula:

$$f = (6M/t^2) - (T/t)$$

TABLE 1 Dimensions of Cast-in-Place Concrete Pipe

NOMINAL DIAMETER (Interior)		OUTSIDE DIAMETER (Depth)		WIDTH OF PIPE/TRENCH (Nominal)		WALL THICKNESS (Minimum)	
D		D'		B		t	
mm	inches	mm	inches	mm	inches	mm	inches
610	24	762	30	787	31	76	3.0
686	27	838	33	864	34	76	3.0
762	30	914	36	940	37	76	3.0
914	36	1092	43	1118	44	89	3.5
1067	42	1270	50	1295	51	102	4.0
1219	48	1473	58	1499	59	127	5.0
1372	54	1651	65	1676	66	140	5.5
1524	60	1829	72	1854	73	152	6.0
1676	66	2007	79	2032	80	165	6.5
1829	72	2184	86	2210	87	178	7.0
1981	78	2362	93	2388	94	191	7.5
2134	84	2540	100	2565	101	203	8.0
2438	96	2896	114	2921	115	229	9.0
2743	108	3277	129	3302	130	267	10.5
3048	120	3658	144	3683	145	305	12.0

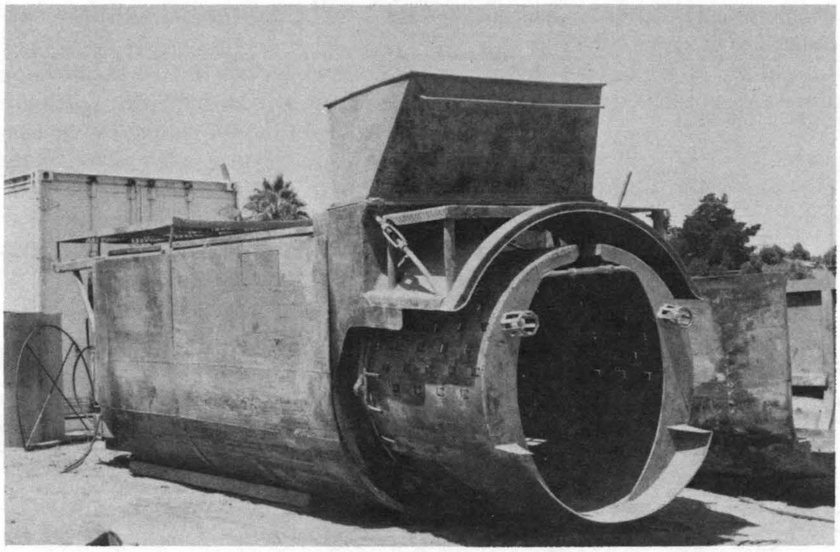

FIGURE 2 Pipe casting machine.

where

M = moment per unit length of pipe (N·m/m),
t = thickness (mm),
T = circumferential thrust per unit length of pipe (m), and
f = stress (MPa).

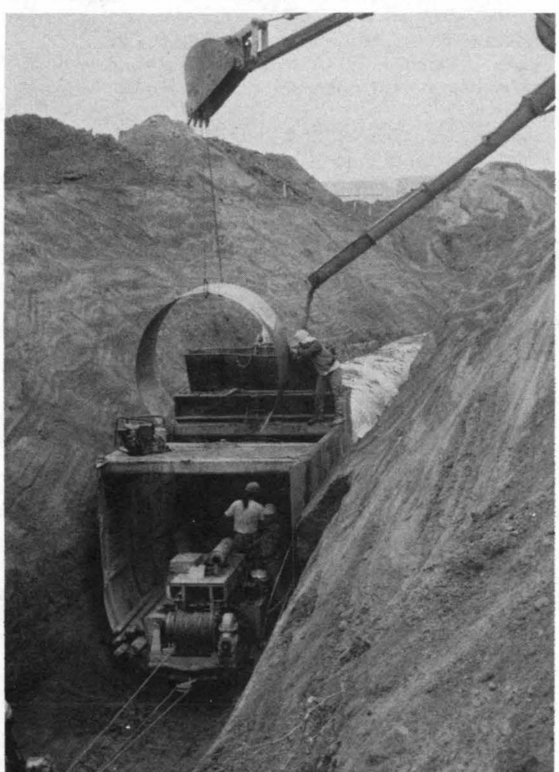

FIGURE 3 Pipe case in prepared trench.

Alternatively, a stress analysis may be obtained from finite element studies, such as CANDE, wherein a round pipe of constant wall thickness may be used to approximate the configuration shown in Figure 1.

FIELD PERFORMANCE STUDIES

The following is a list of studies known to the authors that illustrate the structural performance of CIPCP.

1. Gravity load test performed by Fortier (*5*), 1954, Fresno, California; pipe diameter = 762 mm (30 in.); soil type, sandy loam/silica with cemented hardpan; f'_c = 15.2 MPa (2,200 psi); loading with modified ASTM sand box; visual observation for distress.

Test and results: A 4-ft section was loaded to 288 kN (43,000 lbf). There was no visible cracking.

2. Hydrostatic load test by Fortier (*5*), 1954, Fresno, California; pipe diameter = 762 mm (30 in.); soil type, sandy loam/silica with cemented hardpan; f'_c = 15.2 MPa (2,200 psi); hydrostatic loadings; instrumented with Type IDP marsh gauge with a pressure range of 0 to 0.69 MPa (0 to 100 psi).

Test and results: A 13-ft test section was bulkheaded and hydrostatically loaded. A pipe rupture occurred at 229 kPa (33.2 psi) or 23.4 m (76.7 ft) of head.

3. Shallow burial test by Johnson and Hess (*6*), 1963, Tucson, Arizona; pipe diameter = 1219 mm (48 in.); in situ soil type, cemented sand and gravel; compacted fill around pipe at 100 percent compaction (ASTM T–180), 228 kg/m^3 (143 pcf); cover, 0.15 m (0.5 feet); f'_c = 27.5 MPa (4,000 psi); truck axle and wheel loads; instrumented with strain gauges, dial gauges, and Carlson pressure cells.

Test and results: A maximum wheel load of 125 kN (28,000 lbf) was applied. No distress was observed visually or by instruments.

4. Shallow burial, early live load field test by Gabriel (*7*), 1964, Sacramento, California; pipe diameter = 1830 mm (72 in.); in situ soil type, partially cemented sandy silt; cover, 300

mm (12 in.); 3-day f'_c = 10.3 MPa (1,500 psi); truck axle loads; instrumented with deflection gauges.

Test and results: An axle load of 142 kN (32,000 lbf) was applied after 3 days. No distress was observed visually or by instruments.

5. Field load test by Gabriel (*8*), 1967, Sacramento, California; pipe diameter = 2134 mm (84 in.); in situ soil type, caliche hardpan; f'_c = 20.7 MPa (3,000 psi); early live loads with compaction equipment; instrumented with strain gauges and deflection gauges.

Test and results: Backfilled to 3.7 m (12 ft) and compacted with standard equipment 4 days after pipe was cast. No distress was observed visually or by instruments.

6. Shallow burial load test by Lum (*9*), 1969, Honolulu, Hawaii; pipe diameter = 610 mm (24 in.); in situ soil, stiff red clayey silt; 7-day f'_c = 22.7 MPa (3,292 psi); cover, 0.3 m (1 ft) over CMP, 0.0 to 0.3 m (0 to 1 ft) over concrete pipes; tractor-scraper wheel loads; instrumented with deflection gauges.

Test and results: A 200-kN (45,000-lbf) wheel load was moved over CIPCP, RCP (Class IV), and CMP. No distress was observed in concrete pipes; deflection of RCP was 8 to 10 times that of CIPCP. Large vertical and horizontal deflections of CMP were visually observed.

7. Zero cover static load tests and shallow cover, 0.3 m (1 ft), for dynamic tests by White and Underwood (*10*), Dallas, Texas, 1969; pipe diameter = 2440 mm (96 in.); f'_c = 40.9 MPa (5,920 psi); soil type, clayey sand; sand boxes (static tests) with hydraulic jacks, dynamic loads with falling weights; instrumented with strain and deflection gauges.

Tests and results: Static loads up 912 kN (205,000 lbf) were applied; no cracks were observed visually or by instruments. Dynamic loads up to 65 kN-M (48 ft-kps) were applied; no cracks were observed visually or by instruments.

8. Shallow burial field load test by Gabriel et al. (*11*), 1987–1988, Sacramento, California; pipe diameter = 1830 mm (72 in.); in situ soil type, hard silty clay; f'_c = 27.6 MPa (4,000 psi); cover: 0.5 m (20 in.); compaction equipment loading; instrumented with strain gauges, dial gauges, and pressure cells.

Test and results: Deflections and strains successfully measured the effects of 2+ times H2O loading. Instruments sensed a possible crack; however, none were observed visually.

CONCLUDING REMARKS

The success of CIPCP, as shown in the preceding section, offers evidence that when passive trench wall forces in the vicinity of the springline may be counted upon to develop an archlike response in the pipe to vertical loads, tensile stresses are kept below the cracking threshold. This permits economically efficient use of unreinforced concrete for culverts, pipelines, and other underground structures.

REFERENCES

1. *Recommendations for Cast-in-Place Nonreinforced Concrete Pipe*. ACI 346R–90. American Concrete Institute, Detroit, Mich.
2. *Cast-in-Place Concrete Pipe Process* (Lynch Manual). Tremont Equipment Co., Inc., Dixon, Calif., 1990.
3. Paris, J. M. Stress Coefficients for Large Horizontal Pipes. *Engineering News-Record*, Vol. 87, No. 19, Nov. 10, 1921, pp. 768–771.
4. Young, W. C. *Roark's Formulas for Stress and Strain*, 6th ed. McGraw-Hill Book Co., 1989.

5.* Fortier, E. C. *Tests on 30-inch No-Joint Concrete Pipe*. Unpublished report. Fresno, Calif., June 1954.

6. Johnson, M. A., and J. D. Hess. Load Testing of No-Joint Cast-in-Place Concrete Pipe, In *Highway Research Record 30*, HRB, National Research Council, Washington, D.C., 1963, pp. 20–40.

7.* Gabriel, L. H. *Load Testing of 72-Inch No-Joint Cast-in-Place Concrete Pipe with Shallow Cover*. Unpublished report. Sacramento State College Foundation, Sacramento, Calif., 1964.

8.* Gabriel, L. H. *A Study of Displacements of No-Joint 84-inch Cast-in-Place Pipe Soon After Construction*. Unpublished report. Sacramento State College Foundation, Sacramento, Calif., 1967.

9.* Lum, W. *Report of No-Joint Concrete Pipe Field Test Demonstration—Strength of 24-inch Pipe at Mililani Subdivision*. Unpublished report. Honolulu, Hawaii, Mar. 1969.

10.* White, A., and A. C. Underwood. *Field Sand Box Tests*. Unpublished report. Underwood and Associates, Houston, Tex., 1969.

11.* Gilley, C., L. Gabriel, and R. Standley. Field Test of 72 in.-Diameter Cast-in-Place Nonreinforced Concrete Pipe. Paper No. 26533. *Journal of Transportation Engineering*, ASCE, Vol. 118, No. 1, Jan./Feb. 1992.

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