Development History and Characteristics of the Bar-Wrapped Concrete Cylinder Pipe

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ABSTRACT

Bar-Wrapped Concrete Cylinder Pipe (CCP), and the reasons why its configuration enhances its structural performance, may not be widely understood even though it has a long history of service. CCP steel reinforcement consists of a steel cylinder and a continuous mild-steel bar helically wrapped around the cylinder. CCP also has a centrifugally–cast concrete or cement mortar lining and a dense cement mortar coating which encases the steel cylinder and bar reinforcement.

In addition to the steel cylinder, the bar reinforcement provides the balance of steel reinforcement for internal pressure design and it transforms the pipe wall into a composite structure by mechanically locking the mortar coating tightly against the steel cylinder; this feature was identified during initial testing for the development of the pipe and its specifications. This composite construction increases the pipe's stiffness and the external load-carrying capacity since it increases the ring flexural strength of the pipe, which in combination with the passive earth pressure on the sides of the pipe resists the external loads by limiting pipe deflection. The composite construction also increases the pipe's rigidity and resistance to physical damage and corrosion which are very desirable attributes for water transmission pipelines.

The history of CCP and its development milestones since the introduction of the product in 1942 by a US West Coast pipe manufacturer (American Pipe and Construction Company whose name was changed later to Ameron) will be presented; in the late 1940's other pipe manufacturers started producing CCP. Pipe diameters were initially limited to 42 inches and gradually increased to 72 inches as more performance record was developed. CCP development coincided with the use of Carnegie Steel joints with rubber gaskets on the US West Coast in 1940. Performance testing by American Pipe and Construction Company and a few agencies, and early CCP standards prior to the development of the AWWA C303 Standard are reviewed.

This paper presents the design concepts of CCP and details its complete components including the joints. The paper also reviews the performance record of CCP and a few major installations. Good practice installation recommendations are also given.

INTRODUCTION

Bar-wrapped concrete cylinder pipe (CCP) is a semi- rigid pressure pipe designed as a composite structure combining the tensile strength of steel with the compressive strength and corrosion–inhibiting properties of portland cement mortar. Components of CCP are shown in Figure 1. The components are: a steel cylinder (A) with steel bell and Carnegie spigot rings (B) and (C) welded at the ends is lined with centrifugally cast cement mortar or concrete (D). A continuous mild steel bar (E) is helically wrapped around the cylinder and secured by welding to the joint rings at each end. A dense cement mortar coating (F) encases the cylinder and bar reinforcement. A round rubber gasket (G) is placed in an annular groove in the spigot ring just prior to field assembly. A grout band (H) wrapped around the joint and firmly strapped on both sides after field assembly serves as the mold for cement mortar grout (I) poured in the exterior joint space. The interior joint space is pointed (filled) with cement mortar (J).

HISTORY AND MILESTONES DURING DEVELOPMENT OF CCP

During World War II, there were shortages of steel coil and plate for use in domestic infrastructure; the availability of bar reinforcement was slightly better. Therefore, American Pipe and Construction Company (American), a cement mortar-lined-and-coated steel pipe manufacturer, whose name was later changed to Ameron in 1970, developed a pipe in 1942 with bar reinforcement to supplement the steel cylinder area

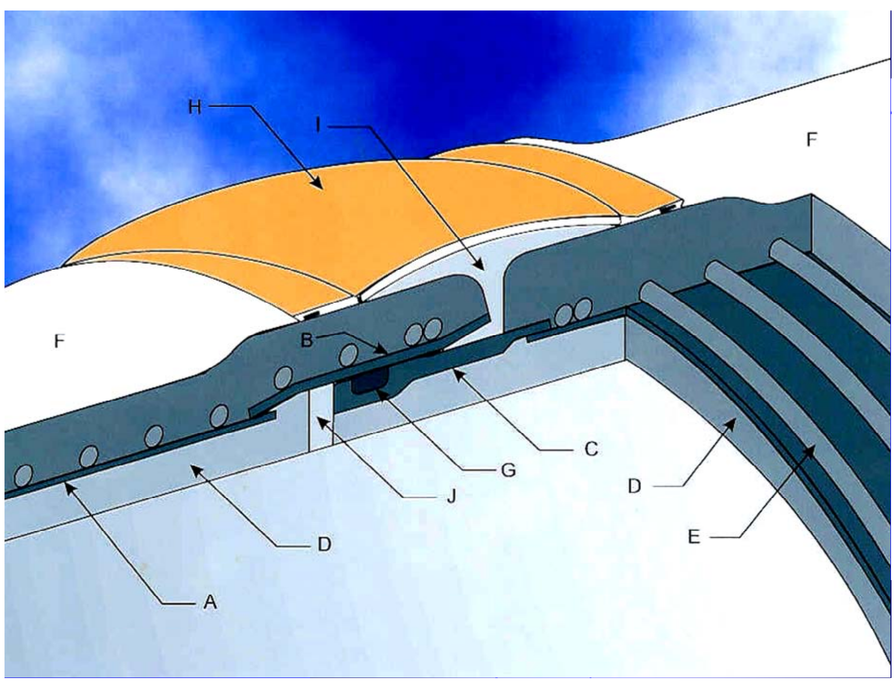

Figure1. Components of Installed CCP.

required to resist the internal hydrostatic pressure. The advantages of this practice, which results in a composite wall structure were demonstrated through product testing and field experience. Other major milestones are:

- The use of Carnegie type gasketed joints, which American had acquired the rights for its use in 1937, and the design and development by American of its helical welding machines for forming continuous steel cylinders up to 3/16-inch in the late 1940's and up to 3/8-inch thickness in the late 1950's were fundamental to the success of CCP as a product.

- The City of San Diego was one of early users of CCP in the early 1940's for their water system for pipe diameter up to 42 inches. Other agencies followed suit including the United States Bureau of Reclamation (USBR) in 1949.

- American developed its own design and manufacturing guidelines until the first US Federal Specification SS-P-00381 was issued on April 2, 1953 which was superseded with SS-P-381 on September 14, 1955. The standard initially covered pipe diameters up to 36 inches and was later extended to include diameters up to 42 inches. The Federal Specification was revised as SS-P-381A in 1967.

- American conducted a series of comprehensive tests on 60-inch diameter CCP in 1953 which were witnessed by an independent inspection company. The test results convinced the Empressa De Acueducto De Bogotá in Colombia to allow CCP as an alternate for the Tibitoc water supply system consisting of approximately 13 miles of 60-inch diameter pipeline in 1955. American was successful in securing the project; this project was instrumental for extending the CCP pipe diameter range from 42 inches to 60 inches.

- In 1970 the name of American Pipe and Construction Company in North America was changed to Ameron. The name in Columbia could not be changed.

- Ameron gradually extended their manufacturing capabilities, particularly the helical forming and welding machines with forming tubes in 1980's up to 0.50 inch steel cylinder thickness which was necessary to produce larger diameter and higher pressure class CCP.

- The CCP diameter range was extended to 72 inches after the AWWA C303 standard was issued in 1970 and the USBR standard in 1972 and US Federal Specifications SS-P-381B in 1979. The USBR have over 300 miles of large diameter CCP projects in their systems. The diameter range in the AWWA C303 was extended gradually, through revisions, to 72 inches.

- Since introduction of CCP in 1942, Ameron and other pipe manufactures such as United Concrete Pipe, Gifford-Hill American (became Hanson in 1994) and others have supplied several thousand miles of CCP pipelines in North and South America, the Middle East and Far East.

PERFORMANCE TESTING OF CCP

This paper covers tests conducted by Ameron (or American until 1970) only and does not cover tests conducted by other CCP manufacturers. The following describes some of the testing:

- Many load deflection tests were conducted by Ameron in the 1940's by encasing the pipe in sand within a frame and then applying an external load by load cells with hydraulic rams through a beam on top of the frame. The pipe deflections were measured through spring loaded dial indicators from inside the test pipe; the set up was similar to the set up shown in Figure 2 except the test pipe was completely encased with sand. The objective of such tests was to fine tune the ratio of bar reinforcement area to the cylinder area and corresponding composite wall properties. Results of one of the test series were presented in October 24, 1951 at the AWWA California Section Meeting in San Francisco (White 1952).

- External crushing strength (external hydrostatic pressure) tests were conducted by one of the users (East Bay Municipal Utility District, Oakland, CA) of bar-wrapped steel pipe with cement mortar lining and coating. The results were presented in the same October 24, 1951 meeting which is referenced above; these tests have shown that the bar-wrapped steel pipe with cement-mortar lining and coating can withstand full vacuum without damage (Paul et al, 1952). The 36-inch diameter pipe was able to withstand 76 psi external pressure before collapsing.

- Ameron conducted three phase comprehensive tests on 60-inch diameter CCP in August 1953 up to January 1954 which was witnessed by Smith-Emery Inspection and Testing Company. The three test phases and their objectives are listed below.

    1. The first phase consisted of conducting hydrostatic pressure tests with test pipe having different ratios of bar to cylinder steel areas. The results showed that the bar reinforcement is more effective than the cylinder alone in distributing the strains in the coating due to internal hydrostatic pressures without visible cracking.

    2. The second phase consisted of three buried pipe sections with 4 ft cover plus additional external loading; two pipe sections were joined before backfilling and the third section was installed and backfilled separately with an inspection pit separating both assemblies. The objective, besides observing the structural performance of the lining and coating under external loading conditions, was to demonstrate that the joint can withstand the external load, and the joint has the ability to transfer load from one pipe to another. The tests were repeated after removal of the backfill and disassembly of the two pipe sections and subsequent reinstallation of the two sections separately with an inspection pit between them; this was performed to ensure that the pipe sections do not support each other under external loading.

Figure 2. Set up for Sand-Bearing Load/ Deflection Tests

3. The third phase consisted of two assembled pipe sections with bulkheads at the ends and tie rods across to hold the internal pressure thrust after pressurizing. The joint area was subjected to a concentrated load to force pipe deflection in the joint area. The objective was to demonstrate the watertightness of the CCP joint under the allowable pipe deflections: the joint was watertight under the maximum loading of the test equipment, which produced more than twice the design allowable pipe deflection.

- Ameron conducted many performance related load deflection tests in the 1960's and 1970's. One notable large diameter CCP test was conducted on 66-inch diameter CCP where the pipe was buried in a trench with compacted loam backfill, 3 ft. cover, and additional external load applied. The interior profiles of deflected pipe, plotted to an exaggerated scale, are shown in Figure 3; the trench profile and external applied load, W, is also shown. Under maximum applied load, equivalent to 17.5 feet of soil cover, both vertical and horizontal pipe deflections were 0. 5 %.

- In 1989 Ameron conducted hydrostatic and sand-bearing tests on 54-inch diameter CCP, which were witnessed by the USBR and the Metropolitan Water District of Southern California. The stress/strain curve for hydrostatic test results for one of the of the 54-inch diameter CCP test pipe sections is given in Figure 4. Strain gauges were attached to the cement-mortar coating, the steel cylinder and bar reinforcement. The applied pressure and corresponding strain reading were recorded by a data logger. Only hairline cracks were observed in the cement mortar coating. The maximum theoretical stress in the steel, corresponding to the applied hydrostatic pressures, was approximately 27,000 lb/inch^2 when the test was terminated.

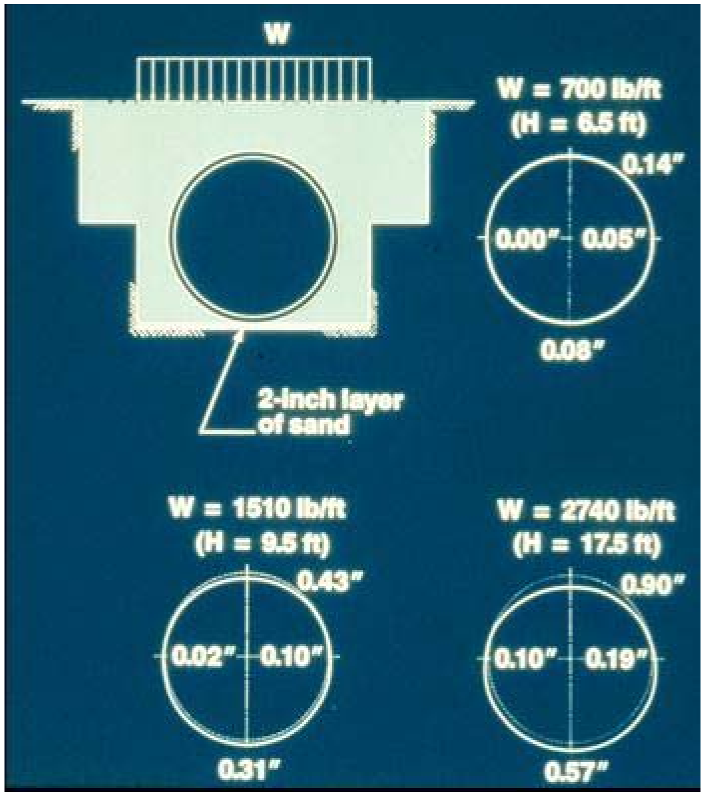

Figure 3. Deflection measurements for buried 66" CCP in a test installation

- In 1999, sand-bearing pipe deflection tests, which were sponsored by Las Vegas Valley Water District (LVVWD), were conducted by Ameron on 36-inch diameter and 54-inch diameter steel cylinder pipe with cement mortar lining and coating with and without bar reinforcement (Bardakjian et al, 2001). Refer to Figure 2 for the test set-up which shows the 36-inch and 54-inch diameter test

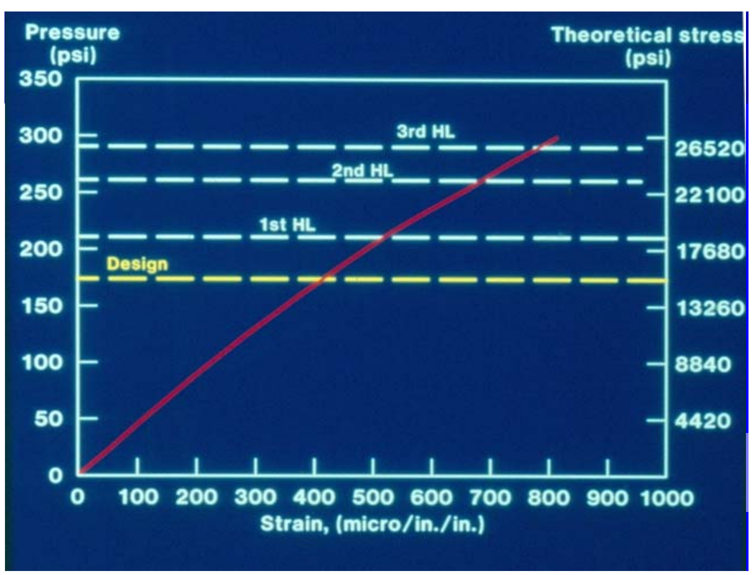

Figure 4. Stress/Strain curve for a hydrostatic test for 54" CCP

pipe side by side. The uniqueness of these tests is that the loads were taken to the maximum capacity of the testing machines or until the lining compression failure occurred. In case of the 36 inch diameter pipe with bar reinforcement, the lining compression failure occurred at 6.5% deflection where the steel may have also reached the yielding point. The maximum load applied for the 54-inch diameter pipe resulted in 5.8% deflection with no compression lining failure. Figures 5 and 6 show the sand bearing load versus the pipe deflection curves for one 54-inch test pipe section with minimum bar reinforcement and one 54-inch test pipe without bar reinforcement, respectively; both pipes have the same steel area. The maximum load applied for the test pipe with bar reinforcement was approximately 8000 lb/ft compared to approximately 5000 lb/ft for the test pipe without bar reinforcement at approximately 5.8% pipe deflection; this verified the effectiveness of the bar reinforcement for improving the structural performance of the pipe.

CCP CHARACTERISTICS

The circumferential mild steel bar, which is helically wrapped around the cylinder at a tensile stress of 8,000 to 10,000 psi, provides the balance of the steel required to resist tensile hoop forces and it also reinforces the mortar coating and locks it tightly against the steel cylinder so that the cylinder, bar, and coating act as a composite structure. Without the bar reinforcement, the wall stiffness will be the sum of the stiffnesses of the three laminar rings, (the lining, the cylinder, and the coating), which is significantly less than the stiffness of the composite wall construction. Other characteristics are:

- Wrapping the steel bar under some tension produces moderate compressive stress in the steel cylinder and cement-mortar lining, thereby increasing the rigidity of the pipe and reducing the effects of drying shrinkage.

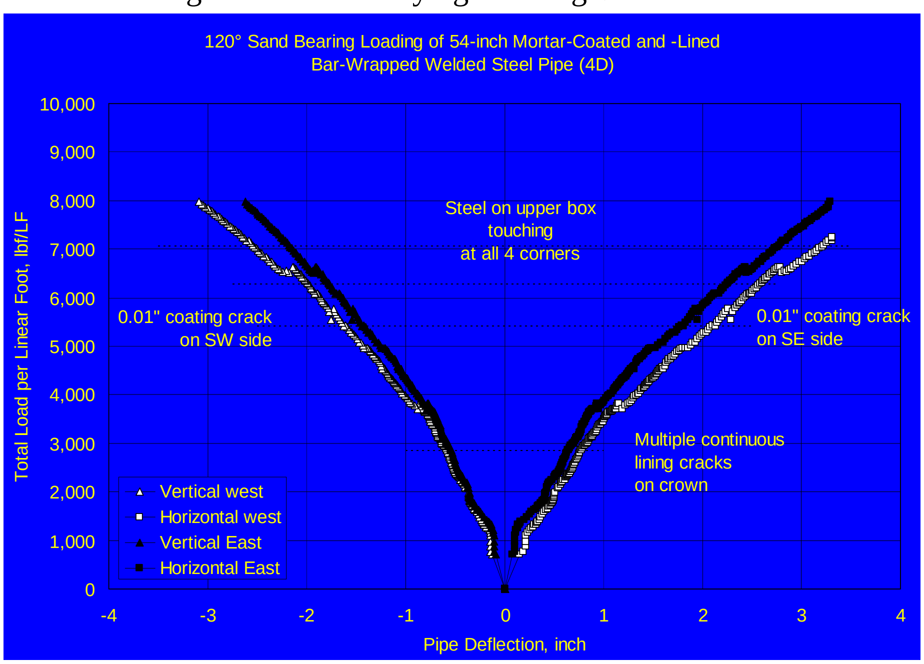

Figure 5. Load deflection curves for 54" CCP

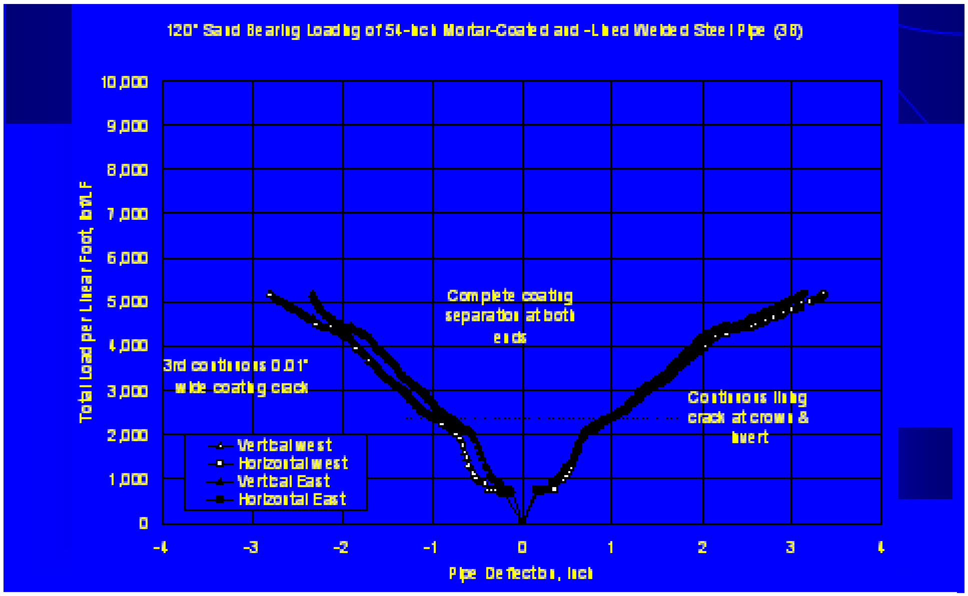

Figure 6. Load deflection curves for 54-inch mortar lined and coated steel pipe without bar reinforcement.

- The composite construction of CCP increases the pipe rigidity and resistance to physical damage, during both handling and installation.
- CCP is inherently corrosion-resistant due to its composite construction and to the unique protective properties of portland cement mortar.
- The bar reinforcement in CCP is more effective than the cylinder alone to distribute the strains in the coating due internal pressure hoop stress.

DESIGN CONCEPTS of CCP

CCP is designed as a composite steel and cement mortar structure. Steel cylinder thickness, bar diameter, and bar spacing are controlled within specified limits to ensure the integrity of the composite design. Hydrostatic pressures are resisted by the steel components of CCP, the steel cylinder and circumferential steel bar. External loads are resisted by the ring flexural strength of the pipe and by the passive earth pressure on the sides of the pipe. Both maximum circumferential stresses and maximum pipe deflections are held to values which will not impair the structural and protective properties of the cement mortar lining and coating. CCP is a semi-rigid pipe, designed in conformance with AWWA C303 Standard and AWWA Manual M9.

PERFORMANCE of CCP

Since its introduction in 1942, several thousand miles of CCP pipelines have been installed in North and South America, the Middle East, and the Far East. The performance record has been very good with very few issues, which have been mainly due to improper installations. A 66-inch diameter CCP installation in 2004 is shown in Figure 7 for a project for San Diego County Water Authority. The trench was excavated mainly through rock foundation by ripping and blasting and the excavated rocks were processed into crushed rock and used as bedding material.

The following are a few examples of recent large diameter CCP projects:

1. A three phase project in Saudi Arabia, the Al-Hunayy Water transmission project, consisted of 320 miles of 48-inch and 54-inch diameter CCP pipeline was completed in 2006.
2. In 2003 and 2004, 52 miles of large diameter, 54 to 72- inch diameter CCP projects were completed in California and Arizona. Some of these projects utilized testable gasketed joints.

INSTALLATION RECOMMENDATIONS

There have been a few isolated issues with a few CCP projects, which were the result of installations without any bedding under the pipe on unyielding foundations or no or poor-haunch support for larger diameter pipe. A similar test to that shown in Figure 3 was conducted to simulate poor haunch support. Instead of compaction by tamping, loam backfill material, which is not self-draining, was water jetted to produce the poor haunch support. At the maximum load applied, equivalent to 7.5 ft of cover, the vertical deflection was 2.6%, and reverse curvature damaging the lining and coating occurred in the bottom of the pipe. The following are a few installation recommendations:

- The use of water jetting in cohesive backfill soils is not recommended; water jetting has been used successfully for consolidation of self-draining cohesionless soils.
- The installation of pipe without any bedding on unyielding foundations is not a good practice and will result in pipe damage. The bedding material under the pipe should

Figure 7. Installation of 66-inch diameter CCP

include at least a 2- inch layer of loose sand or unconsolidated material that can provide a yielding foundation for better external load distribution.

CONCLUSIONS and OBSERVATIONS

The following are a few conclusions and observations:

- The Composite wall construction of CCP is a desirable feature since it increases the pipe stiffness and consequently its external load carrying capacity, due to the increase in the ring flexural strength of the pipe.
- The composite wall construction of CCP also increases its resistance to physical damage, over deflection, and corrosion, which are very desirable attributes for water transmission pipelines.
- The bar reinforcement of CCP is more effective than the cylinder alone in distributing the strain in the coating resulting from internal pressure. This is similar to the bar steel area used in reinforced concrete cylinder pipe, where a portion of the required steel area has to be provided as bar reinforcement.

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