Analysis and Testing of a Prototype Jointing System for Bar-Wrapped, Steel Cylinder Concrete Pressure Pipe

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ABSTRACT

Northwest Pipe Company is a manufacturer of both steel pipe and bar-wrapped steel-cylinder concrete pressure pipe. While there are similarities between the two pipe materials, the AWWA C303 standard for bar-wrapped concrete pipe does not currently allow the Rolled Groove gasket joint, a rubber sealing system widely used in steel pipes manufactured with complete-penetration butt welded seams per AWWA C200. In an effort to study the viability of including the Rolled Groove joint into Bar-wrapped concrete pipe, the services of researchers from the University of Texas at Arlington were retained to aid with design and analysis of a prototype joint, S303™. Additionally, full scale tests on a 54-inch S303 prototype joint were conducted to verify its ability to perform to established acceptance criteria. This paper presents discussions on the Finite Element Modeling (FEM) and the full scale testing.

INTRODUCTION

Similarities exist between Bar-Wrapped, Steel Cylinder Concrete Pressure pipe (bar-wrapped pipe) manufactured per AWWA C303 (AWWA 2008a) and cement mortar lined-and-coated Steel Pipe made to AWWA C200 (AWWA 2005); these include design theory and methods, manufacture processes, pipe stiffness, and corrosion protection offered by the cement-mortar lining and coatings. However, while both AWWA C303 and C200 allow the use of Carnegie-type gasket joints, the former does not accommodate the Rolled Groove-type gasket joint, an integral rubber sealing system that is commonly used in steel pipes.

Northwest Pipe Company has fully developed the art and science of manufacturing steel pipe with the Rolled Groove-type jointing system through more than fifty years of

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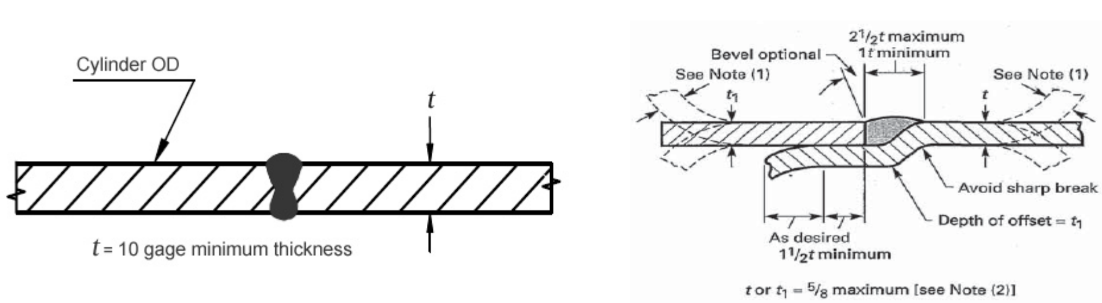
experience with the joint (Kelemen et. al 2011). Since the company also manufactures bar-wrapped pipe, an initiative was undertaken to study the technical feasibility of incorporating the Rolled Groove joint into bar-wrapped pipe. To this end, the company engaged the services of researchers at the University of Texas at Arlington to aid with design and analysis, followed by full scale testing of a prototype joint. Given the trade name S303™, the joint was first developed and analyzed through Finite Element Modeling (FEM), following which full scale testing was performed on a 54-inch diameter joint of two 25-ft long sections of pipe. This paper provides a clear understanding of bar-wrapped pipe, the basis on which it is designed, and in particular, discusses those topics that are pertinent to the successful inclusion of the Rolled Groove-type joint into bar-wrapped pipe. Details of full scale testing performed by the University of Texas at Arlington are provided.

BAR-WRAPPED PIPE OVERVIEW

Bar-Wrapped, Steel Cylinder Concrete Pressure Pipe (bar-wrapped pipe) is produced per
AWWA C303 (AWWA 2008a) in sizes of 10-inch through 72-inch and is designed per the
AWWA M9 Concrete Pressure Pipe Design Manual (AWWA 2008b). Bar-wrapped pipe is
typically manufactured with a steel cylinder ranging in thicknesses of 16 to 8 gage,
depending on the pipe diameter and internal pressures, with an offset lap weld or helical
complete-penetration butt weld from coil steel. Steel joint rings, or Carnegie bells and
spigots in thickness of 10-gage up to 3/4-inch, are fillet welded to the cylinders. Steel bar
reinforcement is wrapped helically around the steel cylinder to provide a total area of steel,
A_s, required to resist internal pressures. In areas of thrust and fittings, thicker cylinders and
or double welded joint rings are typically provided to handle additional longitudinal stresses.
Restrained joint systems include inside diameter (ID) full fillet welds of "trimmed" Carnegie
spigots, outside diameter (OD) fillet welds utilizing filler bars and skip welds, or harnessed
joints – according to Figures 9-24 and 9-25 in the AWWA M9. The steel cylinder is lined and
coated with cement mortar over the metal surfaces for corrosion protection. Pipes are
generally made in lengths ranging from 24-ft to 40-ft, and vary based on a manufacturer's
capability. However, AWWA C303 limits pipes of 18-inch diameter and smaller to a nominal
laying length of 36-ft and pipes larger than 18-inch to a nominal laying length of 45-ft.
Fabricated fittings are welded into pipe sections or shipped separately.

CYLINDER FABRICATION

AWWA C303 allows both complete-penetration helical butt welds, Figure 1a, and offset lap welds per ASME Code Section VIII Figure UW 13.1 (i), as detailed in Figure 1b.



Figures 1a and 1b: Helical Butt Weld, Helical Offset Lap Weld (ASME 2007)

The offset lap weld does not realistically allow for manufacturing of a rolled groove joint. The two thicknesses of metal at the helical seams do not allow for a precise rolled groove unless one thickness of metal is removed. This is one reason why Carnegie joint rings are the joint options for the offset lap welded cylinders. Complete-penetration butt welded seams do allow the precision Rolled Groove joint to be manufactured

BAR WRAPPED PIPE JOINTING SYSTEMS

AWWA C303 bar-wrapped pipe has successfully utilized Carnegie bell and spigot jointing systems as detailed in Figure 2 for many years. Carnegie joint rings are welded to a relatively thin cylinder via fillet welds. Welding of this joint ring is critical to the water tightness and service life of the bar-wrapped pipe itself. This is especially true if the joint will be field welded and/or harnessed to resist horizontal thrust.

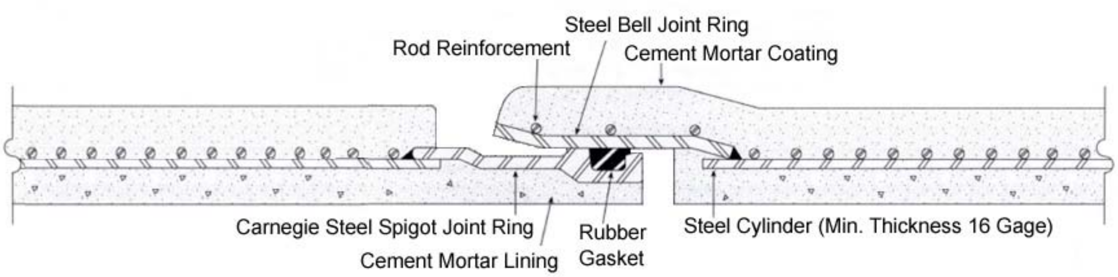


Figure 2: Cross-section of AWWA C303 Bar-wrapped Pipe Joint (not-to-scale)

When joint restraint is required in a bar-wrapped piping system, internal restraint can be provided by full fillet welds of "trimmed" Carnegie spigots, outside restraint can be accomplished by fillet welds utilizing filler bars and skip welds. A third option is to use harnessed joints. Appropriate figures are shown in AWWA M9, Figures 9-24 and 9-25.

S303™ ROLLED GROOVE JOINT PROTOTYPE

The S303 rolled groove gasket joint innovates bar-wrapped pipe by foregoing reliance on a joint welded to the cylinder and instead, joins pipe using a system integral to the cylinder wall, Figure 3. The groove is precision rolled into the spigot end of the pipe by a controlled cold working method that has been used successfully since the 1960's (Kelemen et al 2011). The bell end of the pipe is swedged over a die for precise diameter control during the hydrostatic testing process. S303 joints are compatible with AWWA C303 joints and can be designed to be readily connected to both new and old C303 pipe. As stated previously, the offset lap weld of the helical seams does not realistically allow the manufacturing of a rolled groove and is a key reason this joint is not currently in C303. The successful design and testing of the S303 joint means bar-wrapped pipe standards can now incorporate the proven non-restrained joint technology of the rolled groove joint in pipe with butt welded helical seams and a minimum 10 gage cylinder. Meanwhile, the AWWA C200 standard Section 4.13 is recommended for dimensions, quality control etc. since the Rolled Groove joint is not currently included in the C303 standard.

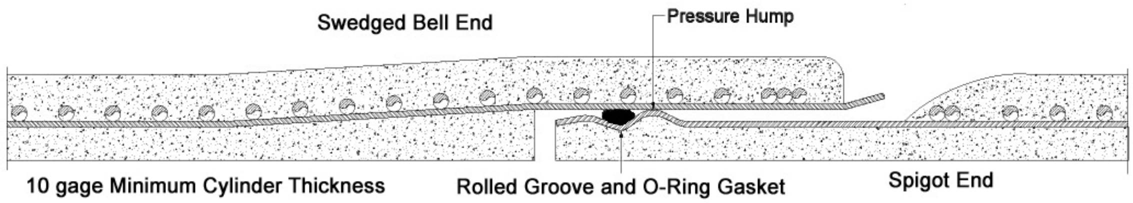


Figure 3: S303™ Rolled Groove Test Joint Profile (not-to-scale)

ANALYSIS AND TESTING OF THE S303™ PROTOTYPE

Since Rolled Groove joints are not currently in the AWWA C303, and due to the fact that a section of the spigot cannot be directly reinforced with bar, a research/testing program was initiated to verify the joint's acceptability for use on C303 bar-wrapped pipe and for possible inclusion in the AWWA C303 Standard. The University of Texas at Arlington (UTA) was commissioned to verify the performance of the Rolled Groove joint on bar-wrapped pipe (UTA 2011). The goals of the research project were to first assist in the design and analysis of the joint through Finite Element Modeling (FEM), followed by a full scale test of the prototype joint to verify its performance and acceptance criteria.

Finite Element Modeling: 3-dimensional nonlinear Finite Element Models (FEM) was created using the ABAQUS/CAE Version 6.9-1 software. The FEM employed a nonlinear incremental solution algorithm called the modified Netwon-Raphson method, and was capable of simulating material, geometric, and contact nonlinearities. An iterative process to approach one root of a function under specified conditions was widely used in the model.

Joint FEM: The Joint FEM was created to understand the behavior of the rolled groove spigot and bell of the S303 joint. Since an area between the bar reinforcement and the pressure hump, Figure 3, would be unreinforced, a model that predicted the influence of stiffness provided from the pressure hump and the bar wrap reinforcement(s) was used. An optimal stab depth (described as the distance the spigot is inserted into the bell) and number of bar wraps on the spigot was determined. The FEM accounted for the main components of the bar-wrapped pipe, including the steel cylinder, inner mortar lining, outer mortar coating and circular or ring steel bar-wraps. Flexibility of the rubber O-ring gasket was not included as its use would have produced lower stresses in the FEM and in an actual application. Figures 4a through 4e shows FEM details for the spiral bar wrap in the bell, mortar in the bell, spiral bar wrap in the spigot, mortar in the spigot, and the whole joint structure, respectively.

For analysis, self-weighted dead loads were considered since it affected the results. Fluid pressure was modeled as an applied area pressure on the interior wall of both the spigot and bell sections. Hydrostatic pressure progressed from 0 psi to 300 psi in 30 psi increments. Steel and Mortar were the two distinct materials used in FEM. Elastic-perfect-plastic constitutive model was chosen to simulate the nonlinear behavior of steel. For the mortar material, the brittle cracking model for the concrete in ABAQUS was used since it provided a capability for modeling concrete-like material in all types of structures. At the same time, it was designed for applications in which the behavior was dominated by tensile cracking and fitted the analysis well.

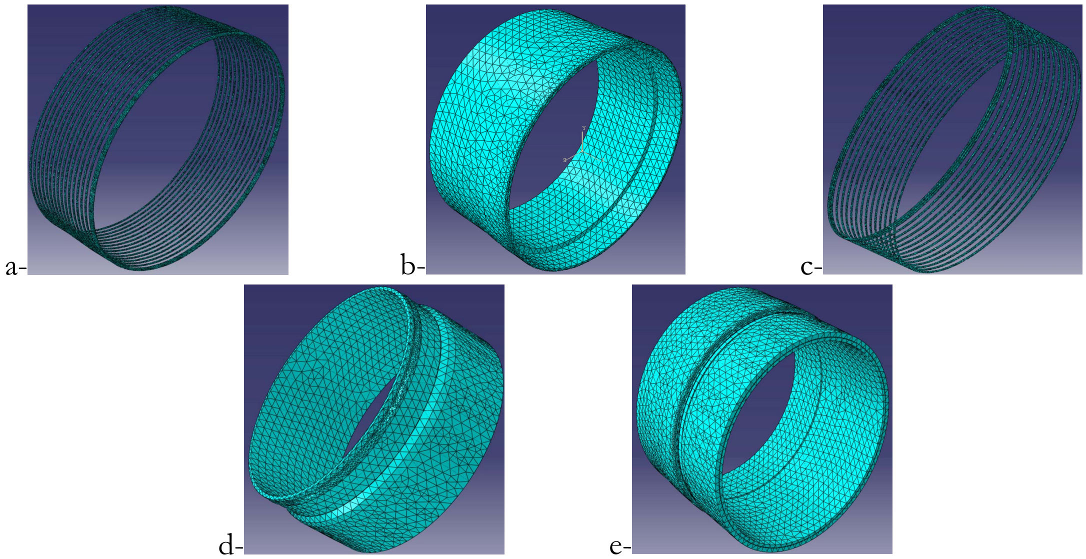


Figure 4a, b, c, d, e: Finite Element Model Details for S303™ Joint

Figures 5a and 5b detail the anticipated Von Mises stresses at 150 psi and 225 psi, (the working pressure and the transient pressure), respectively. This modeling ultimately enabled design of the S303 joint shown in Figure 4.

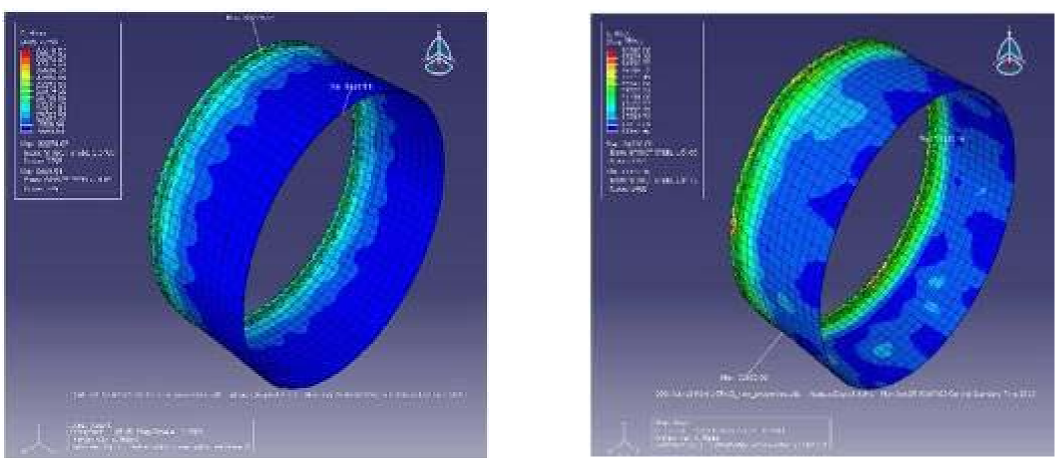


Figure 5a, b: Von Mises Stresses on Spigot End at 150 psi, at 225 psi

Full Scale Testing: Full scale verification tests were conducted on a 54-inch diameter, Class 150 joint. All test pieces were manufactured to current AWWA C303 standards as it relates to minimum cylinder, rod-wrap diameter and spacing, cement mortar lining and coating thicknesses. The cylinder material was made of ASTM A1011-structural steel grade (ASTM 2010) with minimum yield stress of 42,000 psi. The rod-wrap material was made to an ASTM A615-Grade 40 (ASTM 2009) with maximum carbon content of 0.30 percent. The mortar used for the lining had a minimum compressive strength of 4,500 psi at 28-days. Cement mortar coating absorption was also measured. Both the cement-mortar lining compression and mortar coating absorption met AWWA C303 standard requirements. Though the FEM was for a straight joint, a 1-inch pull was used in the full scale test joint to reflect the worst case scenario of an angularly deflected joint in the field. Both test pieces were 25-ft in length, with a total test length of 50-ft, Figure 6a and 6b.

Figure 6a, b: Test Setup with Assembled Joint

One pipe section had a spigot section with a S303 rolled groove gasket joint while the other pipe section had a swedged bell end, as shown in Figure 7.

<u>Acceptance Criteria</u>: Acceptance criteria for the joint included no leakage or deformation at 150 psi working, 180 psi field test or 225 psi transient pressures. The joint was also required to be watertight to 300 psi which represents a factor of safety of 2 over working pressure.

Figure 7: Swedged Bell and Spigot with a Rolled Groove Prior to Assembly

<u>Data Gathering</u>: The prototype was instrumented for measurement of strains at the spigot end in the joint area and overall external deformation during the testing, Figure 8. Internal strains in the steel cylinders were measured by means of resistance bonded strain rosettes in a rectangular pattern. The external deformations were recorded using a cable displacement transducer placed in three locations around the perimeter, one on each springline of the pipe and one at the top. In addition to deformation data, Acoustic Emission (AE) sensors were placed externally in the spigot wrap to monitor leakage and indicate any damage during the pressurization.

Figure 8: Strain Measurement Instrumentation Attached to Prototype

RESULTS OF FULL SCALE TEST

Due to pump limitations, the maximum pressure attained in the physical test of the joint was 437 psi, without any leakage. Notable bulging was taking place in the non-bar-reinforced portion of the spigot at the joint location by the time 437 psi was reached, however performance of the seal was not compromised at any stage. At transient pressure of 300 psi, which represents a factor of safety of 2 over design pressure, no leakage was recorded.

The recorded strains and the calculated Von Mises stresses from them showed that at 150 and 225 psi of pressure, the steel portion of the spigot had not yielded at either of the critical locations where strain gauges had been placed.

S303™ JOINT RESTRAINT SYSTEM

Lap welded slip joints, as shown in Figure 10, are appropriate for conditions requiring thrust restraint. The welded bell would be formed by expanding the bell end of the joint in a hydraulic expander in a manner similar to steel pipe bell manufacture. The spigot end would require limited preparation and field cut spigot ends could be used. A hydraulic expander is appropriate for lap weld ends as the tolerances are greater than in a rolled groove gasket joint; which, as previously discussed, is swedged over a die. Lap welded joints transmit full thrust loads or full PA through the integral bell without structural concerns of the joint ring, mechanical harness assemblies or attachment of the joint ring to the thin cylinders. Butt-welded cylinders with expanded weld bells and lap welded field joints have a track history of highly successful installations on steel pipe.

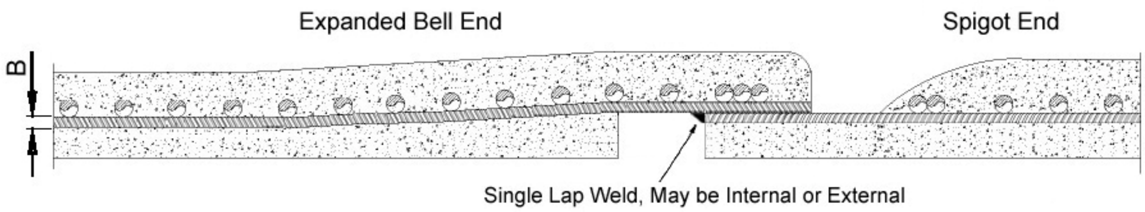


Figure 10: Restrained Single Lap Weld S303 Joint Geometry (not-to-scale)

CONCLUSIONS

While there are many similarities between AWWA C303 bar-wrapped pipe and AWWA C200 steel pipe, the former does not allow the Rolled Groove gasket joint; the latter does. As manufacturers of both steel and bar-wrapped pipe, Northwest Pipe Company engaged the services of researchers from the University of Texas at Arlington to develop an appropriate Rolled Groove joint design for bar-wrapped pipe, first through Finite Element analysis, then verification through full scale testing. The S303™ prototype was successfully modeled, then manufactured and tested and was found to meet all acceptance criteria. The pipe was pressurized to a maximum pressure of 437 psi due to pump limitations, without leakage. It met the target design pressure of 150 psi, transient pressure of 225 psi, and a test pressure of 300 psi, which represents a factor of safety of 2 over design pressure, all without any leakage. The structural integrity of neither the steel cylinder nor any other components of the pipe were compromised up to the 300 psi test pressure. The finite element analysis and subsequent testing indicate the S303 would be a viable jointing option for bar-wrapped pipe.

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