Performance of Gasket Joints in Steel Pressure Pipes

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ABSTRACT

Typical joints specified in steel pipe systems include the non-restrained rubber-gasket-type, restrained field-welded-type, flanges, couplings and expansion joints. Since joints are often perceived as the weak-link in a pipeline, it is important for engineers to have a clear understanding of the capabilities of a particular joint design, quality control practices followed during manufacture, and most importantly, a sound track record of its performance over many decades of use. Gasket-joints are the most common non-restrained jointing system specified not only for steel pipes but also for other commonly-used pipe materials. It is therefore important to have a clear understanding of their design and performance. The two main types of gasket joints permitted by the American Water Works Association (AWWA) Manual of Water Supply Practices M11-*Steel Water Pipe: A Guide for Design and Installation* includes the Rolled Groove type and the Carnegie-type. The former is widely specified for pipe diameters up to 78-inch and 250 psi maximum working pressure, with an allowable maximum transient pressure of 375 psi, though larger diameters and higher pressures can also be accommodated. This paper primarily discusses various aspects of the Rolled Groove joint, but sufficient information is provided on the Carnegie to highlight both similarities and differences.

INTRODUCTION

Steel pipes are widely used in North America in water transmission and distribution applications and are quite arguably a material of choice especially when constructing large diameter pipelines of critical importance. Gasket-sealed joints represent not only the most common non-restrained jointing system for steel water pipe, but also for other commonly-used pipe materials such as concrete, ductile iron, and PVC. Other joint types specified in steel pipe systems include restrained field-welded-type, flanges, couplings and expansion joints. This paper primarily looks at the Rolled Groove rubber gasket joint (Rolled Groove joint). The manufacture process, quality control practices, and installation good-practices are addressed. This paper provides an in-depth understanding of how and why this O-ring sealed integral joint functions. A brief discussion that compares the Rolled Groove joint to the Carnegie-type is also given.

AWWA C200 AND M11 PROVISIONS

Performance Criteria: The AWWA C200 standard (AWWA 2005), in Section 4.13, *Preparation of Ends*, Sub-section 4.13.6, addresses bell-and-spigot ends with rubber gaskets, including those with a formed spigot groove, but defers design to the pipe manufacturer. General performance criteria provided by the Standard require that: 1) the gasket be confined to an annular space so that displacement by pipe movement or hydrostatic pressure does not take place, 2) the sole means by which the joint becomes watertight is by compression of the O-ring gasket, and 3) under all conditions of service, the joint must remain watertight.

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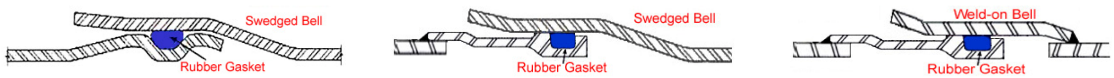
Gasket: The composition of the gasket material is provided, and defined physical / mechanical properties include tensile strength, elongation at rupture, specific gravity, compression set, tensile strength after aging, and shore durometer (or hardness). Sizing of the gasket is not addressed and is deferred to the manufacturer.

Joint Configurations: The C200 standard allows for both the bell and the spigot ends to be integrally formed on the pipe ends, or to be fabricated from separate plates, sheets or special sections which are then welded on to the pipe ends. The AWWA M11 design guide (AWWA 2004) is referenced for various configurations of bell-and-spigot gasket-sealed joints. Figures 1a, b, and c show the three primary types of gasketed joints permitted for use with steel pipe. The first type, referred to as the Rolled Groove joint, is integrally formed on the spigot end of a pipe by roll-forming, while the bell-end is formed by swedging. The second and third types, referred to as the Carnegie joint, are a non-integral steel gasket housing (or spigot ring) that is welded on to the spigot end and combined with a swedged bell, or a spigot ring that is welded to the spigot end combined with a bell ring that is welded on to the other end of a pipe to form the bell.



Figures 1a, b, c: Rolled Groove Joint, Carnegie w/ Swedged Bell Joint, Carnegie w/ Weld-on Bell Joint

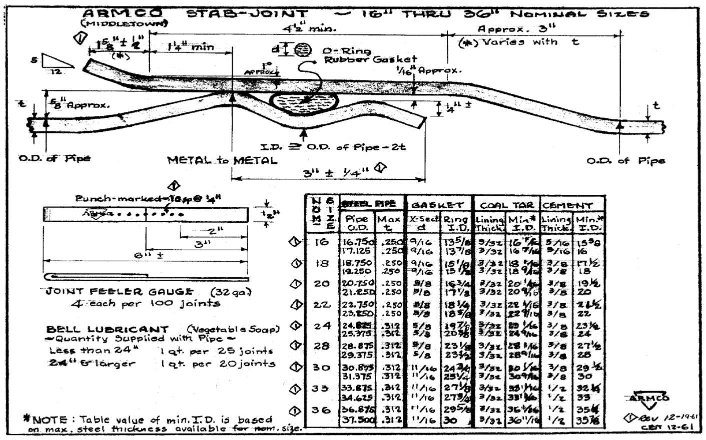
All three configurations meet the performance criteria set forth in the C200 standard and provide appropriate water-tight seals. However, the Rolled Groove joint is the main focus of this paper.

HISTORY OF ROLLED GROOVE JOINTS

Almost twenty years ago, back in 1993, a manufacturer of spirally welded steel pipe in Denver, CO, published an article celebrating the 30th anniversary of their Rolled Groove-type gasket-joint, in which they noted "*An estimated 2.7 million linear feet of O-Tite joint pipe has been installed over the past three decades. Introduced by name in 1963, the O-Tite joint significantly modernized our steel water pipe product*" (TPSC 1993). The company was Thompson Pipe & Steel Company and was to be acquired later by Northwest Pipe Company.

The sealing of municipal pipeline joints with o-rings began in the 1930's. Between 1937 and 1957, for example, O-ring joints, referred to as "roll on joints," were the primary joint-type used in ductile iron pipes. The joint got its name from the use of a compressed rubber gasket that was "rolled" under a restriction ring, that was followed by caulked square-braided jute. With WWII in progress in the 1940's, the Carnegie-type gasket joint was being widely used in concrete pressure pipes. By the 1950's, several steel pipe manufacturers such as Armco Steel, US Steel Company and Bethlehem Steel Company began making pipe where pipe ends were cold formed and sealed with O-rings. While the bells in these pipes were formed, the spigot partially relied on a backing bar that was welded to the pipe to hold the gasket in place. Another version had a V-shaped channel formed into the pipe spigot to hold a gasket.

These were soon replaced with a cold-formed "rolled groove," when in 1956, a predecessor of Northwest Pipe Company, the Beall Pipe & Tank Corporation, introduced a "true formed" O-ring gasket joint in its pipes. Other companies such as United Concrete Pipe and L.B. Foster, also later acquired by Northwest Pipe Company, introduced their own versions of the Rolled Groove joint. By 1962, Armco Steel Corporation's Livermore, CA plant had already installed more than 500,000 LF of steel water pipe with a version of their Stab-Joint™, a Rolled Groove-type joint introduced in late 1958 (Armco 1962). An original drawing of the Stab-Joint™, circa 1961, is shown in Figure 2.



NOM SIZE	STEEL PIPE Pipe O.D.	Max t	GASKET X-Sect d	Ring I.D.	COAL TAR Lining Thick.	Min.* I.D.	CEMENT Lining Thick.	Min.* I.D.
16	16.750	.250	9/16	13 5/8	3/32	[illegible]	5/16	15 5/8
	17.125	.250	9/16	13 7/8	3/32	16 7/16	5/16	16
18	18.750	.250	9/16	15 1/8	3/32	18 1/16	3/8	17 1/2
	19.250	.250	9/16	15 1/2	3/32	18 9/16	3/8	18
20	20.750	.250	5/8	16 3/4	3/32	20 1/16	3/8	19 1/2
	21.250	.250	5/8	17 1/8	3/32	20 9/16	3/8	20
22	22.750	.250	5/8	18 1/4	3/32	22 1/16	3/8	21 1/2
	23.250	.250	5/8	18 5/8	3/32	22 9/16	3/8	22
24	[illegible]	.312	5/8	19 7/8	3/32	23 1/16	3/8	23 1/2
	25.375	.312	5/8	20 3/8	3/32	24 9/16	3/8	24
28	28.875	.312	5/8	23 1/8	3/32	28 1/16	3/8	27 1/2
	29.375	.312	5/8	23 1/2	3/32	28 9/16	3/8	28
30	30.875	.312	11/16	24 3/4	3/32	30 1/16	3/8	29 1/2
	31.375	.312	11/16	25 1/4	3/32	30 9/16	3/8	30
33	33.875	.312	11/16	27 1/8	3/32	33 1/16	1/2	32 1/2
	34.625	.312	11/16	27 3/4	3/32	33 11/16	1/2	33
36	36.875	.312	11/16	29 5/8	3/32	36 1/16	1/2	35 1/2
	37.500	.312	11/16	30	3/32	36 11/16	1/2	35 7/8

Figure 2: Armco Stab-Joint™ Detail, circa 1961 (Armco 1962)

A search of Thompson Pipe and Steel Company's sales records from 1961 through 1996, when it was acquired by Northwest Pipe Company, shows numerous steel pipe projects ranging from 30-inch to 72-inch diameters that were installed and continue to be in service today. Larger diameters have been manufactured and supplied by other Northwest Pipe manufacturing facilities. With more than five decades of proven performance history, the use of the Rolled Groove joint has continued throughout North America.

MANUFACTURE

Bell End: The bell for gasket joint steel pipes is cold-formed by pushing the pipe over a hard faced bell plug die, Figure 3b, during the hydrostatic testing of pipes at the plant, Figure 3a. The bell plug die is attached at one end of the hydrotester, location X in Figure 3a. Figure 3c shows a piece of pipe being belled by pushing over the bell plug die, Y, located at end X of the hydrotester. This method of forming the bell is called swedging. Swedging of the bell by using a die provides a consistent and nearly level inside diameter at the gasket seating area as well as a flare at the end of the bell to facilitate spigot insertion and gasket compression. Using a hydraulic expander for bell formation would not provide the level of consistency that is achieved through the use of a die. It is customary to use an expander for weld bells, but not for the bell of a Rolled Groove joint.

Figure 3a, b, c: Hydrotester, Hardened Bell Plug Dye, Swedged Bell Forming During Hydrotesting

For a typical Rolled Groove joint pipe of 60-inch diameter, the bell would have an engagement depth of up to 8.5-inch. The bell depth, or seating area, also accommodates a spigot pull of at least 1 inch, providing a small amount of longitudinal deflection that can be taken at the joint. It should be noted that the depth of insertion of a Rolled Groove joint is greater than that of a Carnegie-type joint.

Spigot End: The groove on the spigot end of a pipe is cold-formed by rotating the end of the pipe between a set of male and female matched rolling dies. Once the spigot groove is formed, it has a relatively flat bottom with small inside corner radii and is set between two curved shoulders, Figure 4a. The back shoulder is slightly raised and this provides for pipe-to-pipe contact at full engagement in the bell. The relative angularity of the groove serves to seat and confine the o-ring to the annular space as it is compressed, Figures 4b and c. The depth of the groove is dependent on the bell diameter for a particular OD pipe size and will vary with different diameters and wall thickness.

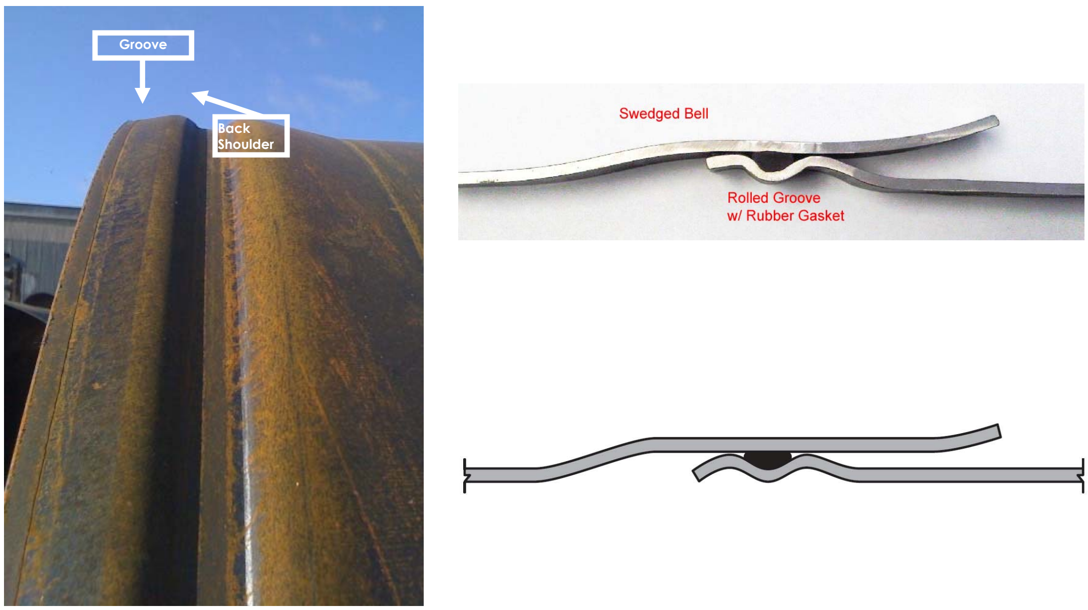


Figure 4a, b, c: Completed Rolled Groove on Spigot, Photo Cross-section of Engaged Rolled Groove Joint, Schematic of Rolled Groove Joint

As with any O-ring gasket system, hydrostatic force behind the gasket induces further compression, thus increasing the sealing action at the gasket interface with the steel surfaces as pipeline pressure is increased. However, hydrostatic pressurization is not necessary to ensure the O-ring gasket seals. The compressive resistance of the O-ring gasket is what makes the joint water-tight, and enables the joint to perform well at low internal pressures also.

QUALITY CONTROL

Hydrostatic Testing of Swedged Bell and Spigot Groove: The rolled groove is typically formed on the spigot end of a pipe before it is hydrotested in the plant. A number of non-destructive tests (NDT) can be employed to ensure the integrity of the formed groove. The swedged bell is formed in conjunction with the hydrotest. So both the formed bell and the formed spigot groove typically undergo hydrotesting in the plant. All affected spiral-weld seams within the joint configuration are ground flush prior to end formation, Figure 5.

Figure 5: Grinding Flush of Spiral Weld Seam in Joint Configuration

<u>Control of Critical Dimensions</u>: The successful design and manufacture of the Rolled Groove joint is an example of the level of sophisticated fabrication employed in the making of non-restrained large diameter steel water pipe. One of the most critical tolerances of a joint is the difference between the internal diameter of the swedged bell, Figure 6a, and the outside diameter of the back spigot shoulder, Figure 6b.

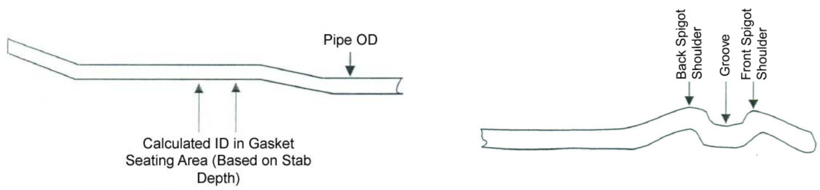


Figure 6a, b: Critical Bell Dimensions, Spigot Dimensions

An O-ring gasket is sized through calculations, with the following guidelines:

1. the stretched gasket cross section will fill the annular space of the spigot groove
2. The gasket diameter is proportional to the groove volume.
3. the circumferential length of a gasket is determined with a stretched length to ensure a tight fit and limit the chances of gasket roll-out during joint assembly
4. since adequate gasket compression is much more critical than gasket volume for proper sealing, a cross-sectional compression of 30% of the O-ring diameter, when stretched, is considered sufficient for water tightness

The allowable tolerance, or "gap," between the OD of the spigot shoulder, Figure 6b, and ID of the bell, Figure 6a, should be uniformly distributed along the entire circumference of the gasket engagement area. The tight tolerance of the joint facilitates this.

Before each production run of pipe begins, bells and spigots are formed on five pieces of pipe, and pertinent information collected on various joint dimensions, which is used to calculate an appropriate gasket size. This is followed by "stab tests" on five assembled joints to verify all critical tolerances. Prior to ordering O-ring gaskets, sizing of the gaskets is reconfirmed based on the results of the actual stab tests. Any anomalies in the spigot groove formation process is revealed during the stab testing, and appropriate changes made prior to making joints for the remaining batch.

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Rolled Groove joint steel pipes are known to undergo vertical deflections in excess of 6% without leaking. The "corrugating effect" of the spigot groove, caused by the changed moment of inertia, I, of the pipe wall cross-section where the groove is formed, adds a desirable measure of stiffness. The joint area is the stiffest section of the pipe and will be more resistant to severe loading and ring distortion than the pipe barrel itself.

EFFECT OF COLD FORMING ON STEEL

Various studies have looked at the effect of cold-rolling on steel during the pipe manufacture process. In the oil and gas industry, pipes formed by U-ing or O-ing processes were shown to have no impact to the function or design of the pipe (Shoemaker 1984, and Maxey et al. 1988). Keil (2010) showed that the physical/mechanical properties of steel do not change in any significant way during the manufacture process of spirally welded steel pipe per AWWA C200. Cold working of the pipe in the formation of bells and rolled grooves for gasket joints does not degrade mechanical properties of the pipe. He also showed that the factors of safety applied to steel water pipe design are not reduced by the manufacture process, and therefore there is no need to limit hoop stress or axial load design for unrestrained Rolled Groove gasket joints.

The study included analysis of two 30-inch nominal diameter spirally welded steel pipe sections manufactured to AWWA C200, with Rolled Groove gasket joints; one test specimen had a wall thickness of 0.149-inch (165 psi design operating pressure) while the other had a wall thickness of 0.207-inch (300 psi design operating pressure). Testing included Charpy impact, yield strength, ultimate tensile strength, elongation (all per ASTM A370-09a), hardness (per ASTM E18-08b) and grain structure (per ASTM E112-96). Test samples were taken from the pipe body, the expanded bell and from the formed gasket section on the spigot. The bell-ends were formed using the swedge method. There were no discernable changes in the Charpy impact, Rockwell hardness, ultimate tensile, elongation, or grain structure properties. Changes in yield strength were also insignificant.

AWWA C200 specifies a minimum radius of 15 x wall thickness of steel cylinder (t), for cold forming pipe bells to be used in lap welded joints. This accounts for stresses from longitudinal forces that pass along the radii of fully restrained lap welded joints. These longitudinal forces are not present in non-restrained gasket joints such as the Rolled Groove type. Rolled grooves are typically formed in steel cylinders with minimum thickness of 10 gage.

JOINT TESTING

Formal testing has been performed on pipes of varying diameters incorporating the Rolled Groove joint over the years. Some of these tests were conducted in the 1980's at the Denver facility of Northwest Pipe Company, Table 1. Additional testing has been done at other plant facilities.

Figure 7 is representative of the "typical" test set-up used for the destructive testing of Rolled Groove joints listed in Table 1. Harness rods were used to restrain the joints during pressurization. The test joints were set up with angular deflections to simulate field conditions.

Table 1: Rolled Groove Joint Testing (NWP 1981, 1985)

	Test 1	Test 2	Test 3	Test 4
Test Date	Sept. 1981	Oct. 1982	Apr. 1984	Dec. 1984
Test Facility	Denver, CO	Denver, CO	Denver, CO	Denver, CO
Pipe Diameter (in)	25.375	31.375	61.625	67.750
Pipe Outside Dia. (in)	25.375	31.375	61.625	67.75
Pipe Thickness (in)	0.188	0.250	0.3174	0.312
Pressure Class (psi)	265	335	215	160
Steel Grade	A36	A139, Gr. C	A139, Gr. C	A139, Gr. B
Min. Yield Point(psi)	36,000	42,000	42,000	35,000
Actual Yield Point(psi)	39,965	46,757	47,689	43,750
Min. Tensile Strength (psi)	58,000	60,000	60,000	60,000
Act. Tensile Strength (psi)	61,268	70,405	74,370	70,043
Pressure @ Failure (psi)	905	950	760	500

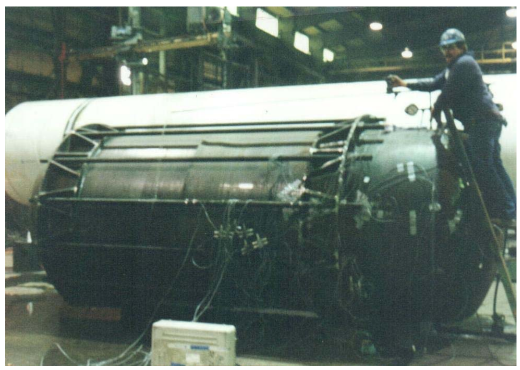

Figure 7: Joint Test Stand Set-up, circa 1984

Test reports of the destructive tests state the pipe samples failed due to yield conditions, i.e. yield strength of the steel was exceeded, before the joint leaked. In all testing results shown in Table 1, it can be seen that the test samples did not fail until pressures were two to three times higher than that which the pipes were designed to handle.

ANGULAR DEFLECTION

The Rolled Groove O-ring gasket joint can be offset or "pulled" a maximum of 1.00-inch, allowing for long-radius curves in pipeline alignment as well as minor offsets during pipeline construction. Maximum allowable angular deflection per joint is limited by the relationship shown in Equation 1.

$$Tangent \leq \frac{Allowable\ Pull}{Pipe\ OD} \qquad \textbf{Equation 1}$$

Allowable angular deflections for pipe diameters of 24-inch and above are given in Table 2.

Table 2: Angular Deflections, based on 1-inch pull (NWP 2005)

Nominal Pipe Diameter (in)	Angular Deflection (degrees)	Nominal Pipe Diameter (in)	Angular Deflection (degrees)
24	2.39	54	1.06
30	1.91	60	0.95
36	1.59	66	0.87
42	1.36	72	0.80
48	1.19	78	0.73

JOINT INSTALLATION GOOD PRACTICES

The quality and effectiveness of a Rolled Groove joint is related to the installation practices of a contractor. Equalizing the tension on the gasket after it is placed into the spigot groove, by inserting a dull instrument such as a dowel or screwdriver shaft under the gasket and completing at least two revolutions around the joint circumference, as well as being cognizant of the importance of evenly bedding and backfilling the pipe to avoid point loading are both good installation practices. It is recommended that a joint be fully engaged to pipe-to-pipe contact. This tends to round the pipe and equalize the gap around the joint circumference. The "corrugating effect" of the spigot groove, caused by the changed moment of inertia, I, of the pipe wall cross-section where the groove is formed, adds a desirable measure of stiffness.

Most critical aspect of installation is to ensure that the O-ring gasket has not been dislodged from the spigot groove during the insertion of the spigot into the pipe bell. It is importance to use a hand-held feeler gauge immediately after joint assembly to verify that a gasket has not rolled out of the groove. The feeler gauge should be inserted under the flare of the bell, making contact with the gasket at a constant, predetermined depth, until the full circumference of the joint has been inspected. A good practice that lowers the changes of dislodged gaskets from occurring is to insert the spigot into the bell in straight alignment. If a rolled gasket is discovered, the joint should be pulled apart and the O-ring gasket discarded. The joint should be reassembled with a new gasket and rechecked with a feeler gauge. AWWA C604 (2011) Installation Guide can be referenced for a more complete installation guide.   NOTE TO NWP the C604 is not published but we still should be able to reference?

FIELD PERFORMANCE & TESTING

For gasket joint steel pipe, AWWA M11 recommends that the test section be filled with water for 24 hours prior to the actual test to enable the lining, if it is a cementitious material, to absorb as much water as possible. The pipeline is then visually inspected for leakage. After this, a test pressure that is not more than 125% of the "actual (or design) operating pressure or pipe class, whichever is the greater" is applied for a 2 hour period. The M11 design manual recommends a test allowance of 10 gal/in-dia/mile/day.

The test allowance not only accommodates the uniqueness of a pipe material but also any initial irregularities in the piping system that may require the addition of more water to maintain the specified field hydrostatic test pressures. The initial absorption of water by cement-based pipe materials or cement-mortar lined steel pipe is an example of a unique material property. Anomalies within a test section that may require additional water to maintain test pressures include entrapped air, faulty connections between the pipe and other appurtenances such as valves, hydrants, fittings and service connections, proper seating of gaskets in pipe and appurtenance, shifting of fittings before joint restraint systems engage, temperature variations, or even instrumentation inaccuracies (Beieler et al 2010).

ROLLED GROOVE & CARNEGIE JOINTS

Carnegie joints perform the same way as Rolled Groove joints in sealing a steel pipe connection, and both are equally time tested. Carnegie-shaped joints with O-ring gaskets were first developed in the 1930's, and with the advent of concrete cylinder pressure pipes during WW II, they became an integral part of concrete pressure pipes; this continues to be the case today. Referred to as "joint rings" in concrete pressure pipe technical literature, the Carnegie type joint is essentially the same whether it is used in a steel pipe or a concrete pipe.

Manufacture of Carnegie Joints: There are several unique steps associated with the manufacture of a Carnegie joint, whether only a spigot ring is used with a swedged bell, Figure 1b, or both a spigot ring and weld-on bell rings are utilized. The main difference between the Rolled Groove and the

Carnegie joint is that the former is fully integral to the pipe, while the latter is not; the Carnegie spigot ring, and if applicable, the bell ring, both have to be fillet welded on the pipe ends. Carnegie joint ring thickness can range from 10 gage up to 5/8-inch. The manufacturing steps are outlined below.

1 – The Carnegie shaped steel material is purchased from a third-party vendor in 20-ft long strips that are formed by hot rolling
2 – Strips of the Carnegie shaped material, butt welded to form the appropriate cut length, are then rolled into the necessary diameter.
3 – The ends of the rolled strip are then welded together to form a ring that is slightly smaller than the necessary diameter.
4 – The Carnegie ring is then appropriately sized by expanding on a sizing die.
5 – It is then fillet welded on to the spigot end of the pipe.
6 – Weld quality is then checked using non-destructive testing (NDT) methods.
7 – If a bell-ring is to be used for a joint, a similar process is followed until it is finally fillet welded to the bell-end of the pipe. Of course the bell ring does not include the pre-formed Carnegie groove.

Some project specifications require that the pipe barrel material match the material of the Carnegie ring. This can present problems as the Carnegie vendor may make the strips from steel material of a differing formulation than that of the pipe itself. Third party acquisition of Carnegie rings makes the process less economical.

The Rolled Groove joint can only be formed on spiral-welded steel pipe where the helical seams of the cylinder have been formed using a full-penetration butt-weld. In cases where the steel cylinder component of a composite pipe are manufactured using lap welding of the helical seams, it is not possible to cold-form the gasket groove on to the pipe. The two thicknesses of metal at the helical seams do not allow for a precise roll groove unless one thickness of metal is removed. Hence, Carnegie joint rings are the only real joint option for offset lap welded cylinders of composite pipes.

CONCLUSION

The Rolled Groove O-ring gasket joint has more than fifty years of successful, proven performance history in North America. Thousands of miles of steel water pipe in transmission and distribution applications have performed very well. The Rolled Groove joint is incorporated into non-restrained AWWA C200 steel water pipe in diameters of up to 78-inch, and working pressure in excess of 250 psi, with a maximum allowable transient pressure of 375 psi. This system that is integral to the pipe allows joint pulls of up to 1-inch, and is economical since joint rings do not have to be purchased or welded on separately. Stringent quality control practices ensure that the Roll Groove joint performs as designed. Cold-forming of the swedged bell and spigot groove do not affect the quality or strength of the steel cylinder; the typical minimum wall thickness of pipe with this joint is 10 gage. Destructive testing of the joint in pipes of various diameters has shown that the steel cylinder itself will rupture prior to the joint when subjected to pressures greater than 3 times working pressure.

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