From: corridoreiswebmaster@anl.gov
Sent: Monday, July 10, 2006 3:06 PM
To: corridoreisarchives,
Subject: Preliminary Draft Corridor Map Comment M0101

Attachments: awwa2004_M0101.pdf

awwa2004_M0101.pdf (1 MB)

Thank you for your comment, CHARLES KAEMPEN.

The comment tracking number that has been assigned to your comment is M0101. Once the comment response document has been published, please refer to the comment tracking number to locate the response.

Comment Date: July 10, 2006 03:06:07PM CDT

Preliminary Draft Corridor Map Comment: M0101

First Name: CHARLES
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Privacy Preference: Don't withhold name or address from public record
Attachment: A:\awwa2004.pdf

Comment Submitted:
The use of a corrosion resistant and impact resistant pipe that can be used at pressures exceeding 3000 psi and are enclosed by a concrete armor to provide protection from terrorists and vandals should be permitted as an alternative to steel pipe that currently is used exclusively to transport gas and petroleum products. Such double-wall pipe is currently available to prevent pipeline leaks caused by corrosion earthquakes, and third party impacts that lead to pipeline failure. The attached technical paper provides details about such a pipe currently available exclusively from Tensionite International, Inc.

Questions about submitting comments over the Web? Contact us at: corridoreiswebmaster@anl.gov or call the Preliminary Draft Corridor Map Webmaster at (630)252-6182.

FIBERGLASS PRESSURE PIPES©

By
CHARLES E. KAEMPEN

A PRESENTATION TO THE CALIFORNIA NEVADA SECTION AMERICAN WATER WORKS ASSOCIATION PREPARED FOR DELIVERY AT THE SPRING 2004 CONFERENCE IN LAS VEGAS NEVADA APRIL 13 – 16, 2004.

SUMMARY

The compressive load capability of a non-buried rigid concrete pipe can be increased substantially if the pipe can be made to perform as a non-rigid pipe that can accept a vertical deflection greater than 2 percent of its diameter.

The cost of a concrete pipe can be reduced if the concrete used to make the pipe wall structure can be placed at the job site after the pipe is connected to adjacent pipe sections.

A unique method has been discovered by which a concrete pipe continues to resist compressive loads after its pipe wall is allowed to crack in a predictable manner thereby permitting the pipe to accept a vertical deflection greater than that which produces the currently acceptable fracture width of 0.01 inch (0.25 mm).

The principal behind this unique method is to enclose the pipe wall concrete in the annulus region of a double-wall fiberglass structure comprising an inner pressure-resisting cylinder and an outer polygonal-shaped cover. The double-wall polygonal-shaped fiberglass pipe is referred to as “Polygon Pipe”. The cracked concrete is retained in place by the outer wall fiberglass panels and remains sealed from external sources of liquid.

A concrete pipe that can accept a vertical deflection equal to 5 percent of its diameter is able to resist a compressive load at least double the load the pipe resists when it is deflected 2 percent of its diameter. Such performance would enable the pipe wall thickness to be reduced, resulting in a lower pipe weight and material cost.

Cost savings also result when the low-weight longer double-wall fiberglass pipe structure, with an empty annulus region, is fabricated, shipped, unloaded, assembled and leak-tested before having the annulus region filled with a high strength concrete.

The results of compressive load tests are disclosed that demonstrate why the site-fabricated “Polygon Pipe” will be able to resist, without a structural leak-producing failure, vertical deflections as great as 9 percent of the pipe diameter. Buried concrete pipe can experience such extreme deflections from soil subsidence, seismic loads , expansive soils, frost loading, flotation, or severe impact shocks that accompany explosions caused by vandals or terrorists. For this reason the “Polygon Pipe” is

recommended as the safest and most economical method to provide corrosion-resistant high performance municipal water and sewer pipe as well as a method to provide a high pressure armored pipe that can be employed to protect new and refurbished gas and petroleum pipelines.

DESIGN OBJECTIVES FOR THE "POLYGON PIPE"

The principal design objective for the Polygon Pipe is to provide a concrete pressure pipe that, when used as an unpressurized rigid pipe, continues to resist compressive loads after it is vertically deflected more than 2 percent of its diameter. A key to attaining this objective is to design a concrete pipe wall that can fracture without losing its compressive strength. This is accomplished by designing the pipe wall as a series of uniformly wide longitudinal flat panels, arranged in a polygonal array around a cylindrical pressure pipe. The flat concrete panels are covered and held in place by a polygonal shaped outer fiberglass cover. The panels are designed to behave as rigid beams that, when subjected to the bending moment stresses resulting from a compression load that produces a vertical deflection greater than 2 percent of the pipe's inner diameter, will crack where the panel thickness is least. One of the design objectives of the Polygon Pipe is to use the AWWA Standard for Fiberglass Pressure Pipe and the AWWA Standards for Concrete Pressure Pipe to guide the performance specifications used in its manufacture, testing and installation. The AWWA M45 Manual of Water Supply Practices "Fiberglass Pipe Design" and the AWWA M9 Manual of Water Supply Practices "Concrete Pressure Pipe" guided the determination of certain Polygon Pipe design criteria. The Polygon Pipe described below meets the principal design objectives and represents a unique composite hybrid that combines the hoop strength and corrosion resistant features of the AWWA C950 Standard for Fiberglass Pressure Pipe with the compressive strength and impact resistant features of the AWWA C300,C301,C302 and C303 Standard for Concrete Pressure Pipe. Another design objective for the Polygon Pipe is to enable it to be made on the job site.

DESCRIPTION OF THE "POLYGON PIPE"

The proprietary polygonal-shaped double-wall fiberglass pressure pipe, having a concrete-filled annulus, is named "Polygon Pipe" due to its multi-sided outer wall shape. By enabling the placement of the pipe's concrete on the job site the Polygon Pipe is able to provide a corrosion-resistant fiberglass-reinforced concrete pipe that is less expensive to fabricate, handle, transport and assemble than conventional steel-reinforced concrete pressure pipe. The polygon shape is produced by an annular array of equally spaced longitudinal steel ribs upon which is wrapped one or more plies of resin-impregnated unidirected fiberglass fabric. This unique configuration enables a liquid concrete slurry , introduced through openings in the outer wall, to flow unimpeded from one end of the pipe to the other . When concrete fills the annular space between the inner pipe wall and the polygon-shaped outer wall, the bottom haunch region of the inner fiberglass pressure pipe is provided a support having a higher soil modulus value than is possible with any compacted backfill soil. The Polygon Pipe has an inner fiberglass pipe that meets the four times use pressure performance criteria outlined in the AWWA C950 Standard for Fiberglass Pressure Pipe . This inner pressure pipe has an inner liner of polyurethane upon which is placed the resin-coated continuous filaments of fiberglass that provide the pipe with the required longitudinal joint strength and circumferential hoop strength. The polygon-shaped outer pipe wall and the longitudinal steel ribs comprising the Polygon Pipe's annulus forming structure provide the concrete pipe with the beam strength and bending resistance that enables an unsupported liquid filled pipe to span distances as great as 60 feet. The double-wall fiberglass pressure pipe, without concrete, can be made, inspected and tested in the shop before it is taken to the job site where, after assembly, the annulus region between the cylindrical inner fiberglass pressure pipe and the polygonal shaped outer wall is filled with concrete supplied by a ready mix truck or other suitable source. Figure 1. is a photograph of an early prototype of the Polygon Pipe.

PIPE DEFLECTION VS. COMPRESSIVE LOAD

The compressive load capability of rigid and non-rigid concrete pipe is a function of its stiffness factor, (SF) and the vertical deflection of its diameter (Y'). The stiffness factor is the product of the concrete's tensile modulus, E, and the moment of inertia, I, of a one inch long section of the concrete pipe wall. Thus SF = EI. The pipe stiffness (PS) that controls the compressive load capability of a pipe is in turn controlled by the pipe's stiffness factor (SF) and the pipe's inner radius, R, according to the formula:
PS = EI / (0.149 R^3). The pipe stiffness (PS) is the ratio of the vertical compressive load, F, and the vertical deflection, Y', produced by the load. For a given pipe product this term is readily determined in the laboratory by a parallel plate loading test. In this test a pipe sample is placed between two horizontal parallel plates in a testing machine, such as shown in Figure 3. A compressive load is applied and increased until the vertical deflection of the pipe inner wall reaches 5 percent of the diameter. The pipe stiffness, PS, is the load at 5 percent divided by the sample length and divided by the vertical deflection. Typical units for PS are pounds per square inch, the same units as the modulus of elasticity, E, of the pipe wall concrete material.
As shown in Table 2, and illustrated in the Figures 4 through 8, when the pipe wall of a concrete pipe is designed so it will experience longitudinal fractures in a predictable manner, the concrete pipe will continue to resist compressive loads after its vertical deflection equals or exceeds 5 percent of its diameter.
Table 3 illustrates the compressive load resistance improvement that results when a non-pressurized concrete pipe, having a specific stiffness factor, is able to accept vertical deflections ranging from 1 to 5 percent.

CONCRETE PIPE STANDARDS

The American Water Works Assn has established standards for three types of rigid concrete pressure pipe. Two of these types, AWWA C300 and AWWA C301 employ an internal steel cylinder coated with mortar. AWWA C 300 uses mild reinforcing steel whereas AWWA C301 uses prestressed wire. AWWA C302 does not have an inner steel cylinder but uses mild reinforcing steel. The concrete wall thickness of AWWA C300 is a minimum of one-twelfth the pipe diameter. The minimum wall thickness of AWWA C301 has a wall thickness of one-sixteenth the pipe diameter. The minimum wall thickness of AWWA C302, the concrete pipe without an inner steel cylinder, is one-twelfth the pipe diameter.

CRACKS IN CONCRETE PIPE

Cracks in certain types of concrete pipe are permitted. External cracks that enable water to penetrate and corrode steel-reinforced concrete pressure pipe are not permitted.

The AWWA M9 Manual of Water Supply Practices relating to Concrete Pressure Pipe states that the limiting horizontal or vertical deflection of a concrete pressure pipe is 0.02 D, where “D” is the nominal pipe diameter in inches. This formula assumes that when the concrete pipe is deflected as much as 2 percent of its diameter the fracture in the concrete pipe will have a crack that does not exceed 0.01 inch in width.

The AWWA Standard C300 for Reinforced Concrete Pressure Pipe, Steel Cylinder Type, states in Section 4.6 concerning cracks on the interior surface: “ Circumferential or helical cracks having a width of 0.06 inches or less are acceptable without repair.” Concerning cracks on the exterior surface of the pipe, Standard C300 states “Longitudinal cracks on the exterior surface having a width of 0.005 inches or less and a continuous length of 18 inches or less are acceptable without repair. “

Longitudinal cracks do not limit the performance of rigid pipe, such as the nonreinforced concrete pipe covered by ASTM C 14 or the reinforced concrete nonpressure pipe covered by ASTM C 76. When the concrete pipe wall material is held in place by the Polygon Pipe’s external fiberglass cover , the pipe performs the same way as brick sewers with no mortar. Brick sewers function structurally, but are not leak proof.

CYCLIC LOAD TEST RESULTS

Conventional fiberglass pipe is made by helically winding upon a cylindrical mandrel a narrow ribbon comprising a multitude of resin-impregnated strands of continuous glass filaments. The load transfer from one layer to the next is a function of the interlaminar shear strength of the resin matrix used to impregnate the filaments of each strand. For this reason, the hydrostatic design basis strength (HDBS) of helically wound fiberglass laminates is governed by the cohesive strength of the resin bonding the multitude of overlapping ribbon plies. Table 1. illustrates the performance of filament-wound fiberglass pipe that is not helically wound but rather is made with only two structural plies. One of these plies consists of unidirected strands of continuous glass filaments oriented parallel to the pipe axis. This ply is termed the "Longo Ply" . The second ply is termed the "Circ Ply" and consists of unidirected strands of continuous glass filaments oriented circumferentially with respect to the pipe axis. This ply provides the material that resists the hoop stresses produced by internal pressure. Table 1 illustrates the long term fatigue resistance of filament wound fiberglass pressure pipe, such as used to make the inner pressure pipe of the “Polygon Pipe”. Table 1. presents the Hydrostatic Design Basis Strength that was determined from cyclic load free-end tests performed on three sizes of pipes having end plugs mechanically connected by fiberglass couplers.

COMPRESSION LOAD TEST RESULTS

Table 2 illustrates the results of compression load tests performed on a one foot long concrete Polygon Pipe having an inner diameter of 18 inch, an average concrete wall thickness of 2 inches and an annulus filled with a low strength concrete. Figure 2 is a photograph of the 18 inch concrete pipe being tested.
Figures 6 and 7 show the type and location of the longitudinal cracks produced in six of the eight concrete panels comprising the Polygon Pipe wall structure that resisted the compression loads presented in Table 2. The width of these cracks were not measured.
Figure 8 shows the appearance of the pipe annulus region when the concrete between the steel annulus ribs is removed.
Figure 5 shows the appearance of the tested Polygon Pipe after the compression load was removed and the pipe inner diameter completely restored as a result of the buckle-resistant spring behavior of the filament wound inner pressure pipe.

Table 3 illustrates the increase in pipe performance that results when the Polygon Pipe is able to resist, without rupture of its inner or outer wall fiberglass structure, vertical deflections greater than 2 percent of the pipe’s internal diameter.

TENSILE LOAD TEST RESULTS

Table 4 presents the Polygon Pipe maximum test pressures for various sizes of pipe that employ an inner pipe having the tensile strength of the 0.295 inch thick inner wall laminate tested by OCM Test Laboratories and shown in Figure 2. Table 4 also presents the dimensions and weights of various pipe sizes having a pipe length of 20 feet.

WHY THE POLYGON PIPE PROVIDES A SAFER GAS PIPE

The U.S. Office of Pipeline Safety oversees the new government mandate that requires wall thickness inspection of aging American steel gas pipelines. The four-times use pressure test requirement characterizing the AWWA C950 Fiberglass Pressure Pipe can, with certain modifications, qualify this pipe as a corrosion-resistant alternative that could replace the steel pipe currently used to transport oil and natural gas. The principal shortcoming of buried steel pressure pipe is its vulnerability to corrosion and accidental rupture caused by drills and backhoes operated by construction crews. The principal shortcoming of buried fiberglass pressure pipe is its lack of stiffness. Surrounding a high pressure fiberglass pressure pipe with an outer concrete wall not only increases the pipe stiffness but also provides a pipe armor that protects against accidental or intentional impact damage that may be caused by contractors or terrorists. The Polygon Pipe can be mechanically connected to have the joint strength of welded steel. Continuous-filament fiberglass reinforcements, such as those used to make the Polygon Pipe, provide one of the strongest and least expensive materials from which to make 3000 psi gas pipe in diameters as large as 72 inches

CONCLUSIONS

The "Polygon Pipe" is a double wall fiberglass pressure pipe enclosed by a polygon-shaped outer cover that seals and configures an array of longitudinal concrete panels that fracture crack when the pipe is subjected to a vertical compressive load that deflects the inner pipe 2 percent of its diameter. The fractured panels enable the inner pipe to deflect as much as 9 percent of its diameter thereby increasing the pipe stiffness and the ability of the pipe to resist greater compressive loads. The Polygon Pipe design enables a concrete pipe to better resist the shocks and higher compressive loads that result from earthquakes or explosions. The concrete surrounding the filament wound fiberglass pressure pipe provides a pipe armor that protects gas and petroleum pipe from accidental or intentional impacts.

The Polygon Pipe contains an annulus forming structure that enables the concrete pipe wall to be fabricated on the job site, thereby reducing the cost of handling, shipping and installation.

The Polygon Pipe is a double-wall filament wound fiberglass pipe that simultaneously meets the AWWA-C950 Standard for Fiberglass Pressure Pipe and the AWWA Standards for Concrete Pressure Pipe, the API 15HR specification for High Pressure Fiberglass Line Pipe and the ASME B31 pipe code requirements for gas and petroleum pipe.

The Polygon Pipe with its concrete annulus is an "out of the box" design that illustrates the synergistic advantages possible by using a combination of structures made from fiberglass reinforced plastic, steel and concrete. It is predicted this pipe will become the paradigm for future municipal , petroleum and natural gas pipe.

CONTACT

Pacific Junction Corporation

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BIOGRAPHY

Charles E. Kaempen is the President of Kaempen Pipe Corporation, Inc., the company that developed the Polygon Pipe introduced in this paper. After completing a one year scholarship in Mechanical Engineering at Stanford University and a one year scholarship in Chemical Engineering at Mexico City College, Kaempen transferred to University of Illinois where he received a B.S. degree in Aeronautical Engineering. Following post graduate studies in orbital mechanics at University of California, Kaempen received a D.Sc. in Astronautics from the International Academy of Astronautics for his invention of the In-Transit Rendezvous method of space travel. Dr. Kaempen holds numerous patents relating to fiberglass composite pipe, tanks and pressure vessels, and the methods and factory equipment with which they are made. Dr. Kaempen is past president of the Orange County Chapter of the California Society of Professional Engineers, a Fellow of the Orange County Engineering Council, and an active member of AWWA, SAMPE, ASCE, ASME, and NSPE.

TABLE 1. Fatigue Resistance of Double-Wall Pipe.

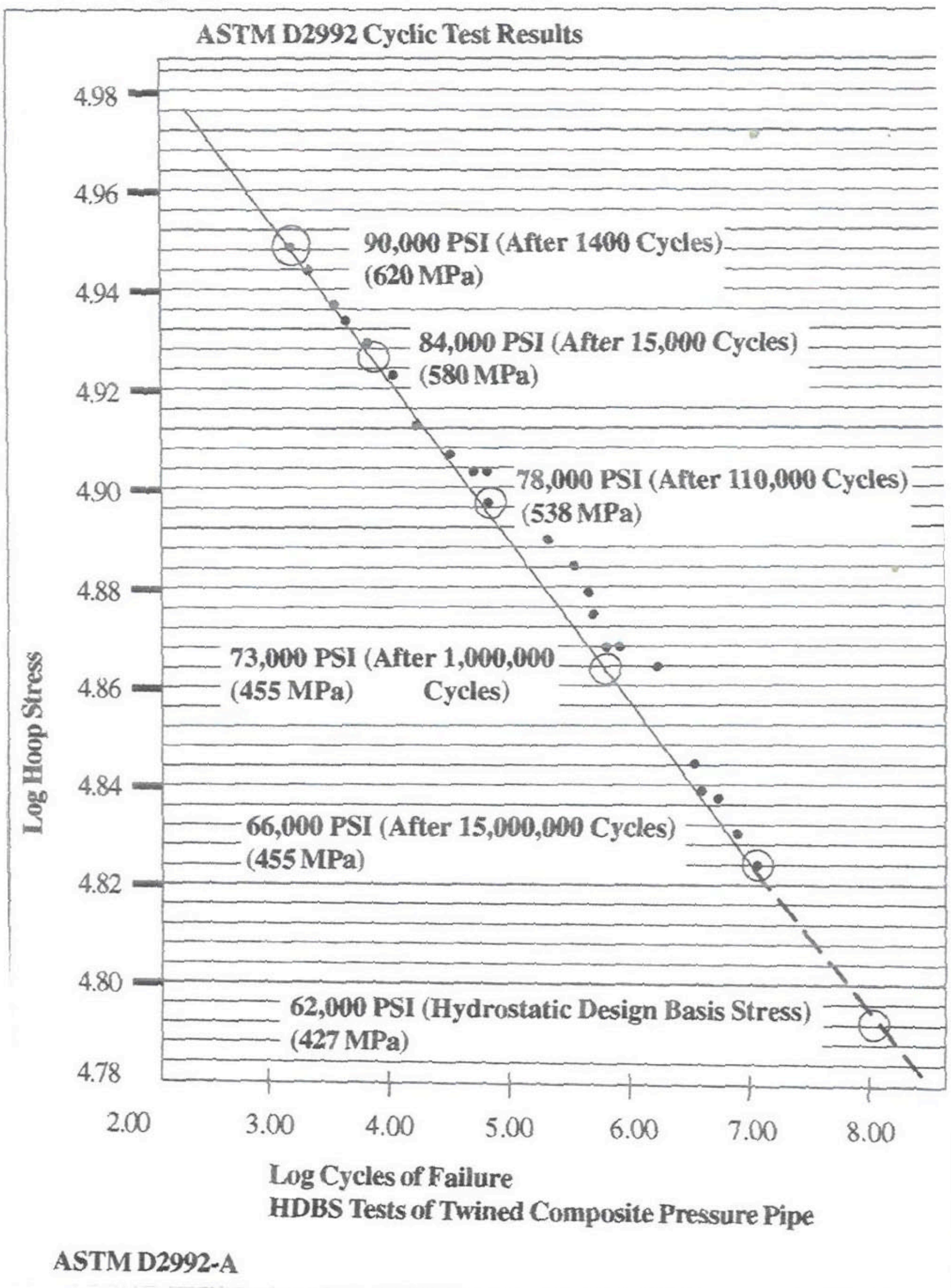

Table 2. Results of 9 Percent Diameter Deflection Test

18 INCH DIA. POLYGON CONCRETE PIPE TEST RESULTS

RFORMED BY OCM TEST LABORATORIES, ANAHEIM, CALIF.

PIPE WALL THICKNESS, **T**, = 2 INCHES ; PIPE RADIUS, **R**, = 9 IN.
I = **T**^3 / 12 = (2)^3 / 12 = 0.67 IN^4 / IN.
E = **PS** *(0.14 9R^3) / **I**
PIPE STIFFNESS (**PS**) EQUALS **E * I** / (0.149 * **R**^3)
PS = F / Y'
NOTE: CONCRETE MIXTURE WAS SAND AND CEMENT (MORTAR)
COMPRESSIVE STRENGTH OF CONCRETE (MORTAR) WAS 1,369 PSI

VERTICAL DEFLECTION **Y'** (INCHES)	VERTICAL DEFLECTION (PERCENT OF PIPE DIAMETER)	COMPRESSIVE LOAD PER LINEAL FOOT (LBS)	COMPRESSIVE LOAD PER LINEAL INCH **F** (LBS)	**PS** PIPE STIFFNESS (PSI)	**E** CONCRETE MODULUS PSI
0.036	**0.2**	2,000	167	4,630	750,560
0.18	**1**	2,400	200	1,111	180,134
0.36	**2**	3,000	250	694	112,584
0.54	**3**	3,700	308	571	92,569
0.72	**4**	4,300	358	498	80,685
0.9	**5**	4,600	383	426	69,051
1.08	**6**	4,600	383	355	57,543
1.26	**7**	4,600	383	304	49,322
1.44	**8**	4,800	400	278	45,034
1.62	**9**	4,880	407	251	40,697

Table 3. Load Performance Increase with Increased Vertical Deflection of Pipe

POLYGON CONCRETE PIPE COMPRESSIVE LOAD PERFORMANCE

NOTE: FOR VERTICAL PIPE DEFLECTION EQUAL TO 1% PIPE DIA. Y' = 0.01
Y' = VERTICAL PIPE DEFLECTION MULTIPLIED BY THE INNER PIPE DIAMETER, (IN)
ASSUME CONCRETE TENSILE MODULUS, **E**, = 3,500,000 PSI
PIPE STIFFNESS (**PS**) EQUALS **E * I** / (0.149 * **R**^3)
PIPE STIFFNESS (**PS**) EQUALS LOAD, "**F**" DIVIDED BY **Y' = F / Y'**
STIFFNESS FACTOR (**SF**) = **MODULUS, E,** x **MOMENT OF INERTIA , I**
PIPE MOMENT OF INERTIA, **I**, = (**T**^3) / 12, IN^4 PER INCH OF PIPE LENGTH
EI = (**SF**) = 0.149 * (**PIPE DIA** / 2)^3 * (**F / Y'**)

ANNULUS WALL THICKNESS = 1/12 PIPE I.D.

PIPE INSIDE DIA. (IN)	LOAD ON 14 INCH LONG TEST SPECIMEN **Y'=0.01** (LB)	LOAD ON 14 INCH LONG TEST SPECIMEN **Y'=0.02** (LB)	LOAD ON 14 INCH LONG TEST SPECIMEN **Y'=0.03** (LB)	LOAD ON 14 INCH LONG TEST SPECIMEN **Y'=0.04** (LB)	LOAD ON 14 INCH LONG TEST SPECIMEN **Y'=0.05** (LB)	NO. OF OUTER WALL SIDES	**"T"** AVERAGE ANNULUS THICKNESS (IN)
12	121,104	242,207	363,311	484,415	605,518	8	2
18	53,824	107,648	161,472	215,295	269,119	8	2
24	30,276	60,552	90,828	121,104	151,380	12	2
30	37,845	75,690	113,535	151,380	189,224	12	3
36	45,414	90,828	136,242	181,655	227,069	12	3
40	50,460	100,920	151,380	201,839	252,299	12	3
48	60,552	121,104	181,655	242,207	302,759	16	4
52	65,598	131,196	196,793	262,391	327,989	16	4
60	75,690	151,380	227,069	302,759	378,449	16	5
72	90,828	181,655	272,483	363,311	454,139	16	6
80	100,920	201,839	302,759	403,679	504,599	16	7
84	105,966	211,931	317,897	423,863	529,828	18	7
90	113,535	227,069	340,604	454,139	567,673	18	8
96	121,104	242,207	363,311	484,415	605,518	18	8
100	126,150	252,299	378,449	504,599	630,748	18	8
120	151,380	302,759	454,139	605,518	756,898	18	10
144	181,655	363,311	544,966	726,622	908,277	18	12

Table 4. Polygon Pipe Dimensions, Weights and Pressure Capability

POLYGON PIPE CHARACTERISTICS USING LAMINATE TEST RESULTS

TENSILE LOAD RESISTED BY 3 PLY TEST COUPON LAMINATE 0.5" WIDE = 2,387 LB
TENSILE LOAD RESISTED BY EACH 0.5 INCH WIDE PLY = 2,387 / 3 = 795 LB.
MAX. HOOP TENSILE LOAD PER INCH OF WIDTH PER PLY = **1,590 LB.**; = **PR**
EACH PLY HAS 8 STRANDS PER INCH OF WIDTH; STRAND THICKNESS = 0.022"
TENSILE STRENGTH OF LAMINATE PLY MATERIAL = 1590/(8*0.0022) = **90,340 PSI**
P = INNER PIPE PRESSURE ; **R** = INNER PIPE RADIUS

PIPE INNER DIA.	MAX TEST P	INNER PIPE WALL THICK.	NO. OF OUTER WALL SIDES	CONCRETE PIPE WALL THICKNESS	INNER PIPE WEIGHT	WEIGHT OF COVER	WEIGHT OF STEEL ANNULUS RIBS	TOTAL WEIGHT OF CONCRETE	WEIGHT PIPE WITHOUT CONCRETE	WEIGHT PIPE WITH CONCRETE
(IN)	(PSI)	(IN)	(NO.RIBS)	(IN)	(LB)	(LB)	(LB)	(LB)	(LB)	(LB)
12	265	0.30	8	3	151	60	278	2,603	489	3,092
14	227	0.30	8	3	176	66	278	2,881	520	3,401
15	212	0.30	8	3	188	69	278	3,113	535	3,649
16	199	0.30	8	3	201	73	278	3,246	552	3,797
18	177	0.30	8	3	225	73	278	2,418	577	2,994
20	159	0.30	8	3	250	85	278	3,825	614	4,439
21	151	0.30	12	3	263	94	418	4,306	774	5,080
24	133	0.30	12	3	300	96	418	4,554	814	5,368
27	118	0.30	12	3	338	106	418	5,067	861	5,929
30	106	0.30	12	3	375	115	418	5,498	908	6,406
33	96	0.30	12	3	412	127	418	6,492	956	7,448
36	88	0.30	12	3	450	136	418	6,740	1,003	7,743
39	82	0.30	12	4	487	151	418	9,539	1,056	10,594
42	76	0.30	16	4	524	160	557	9,986	1,241	11,227
45	71	0.30	16	4	562	170	557	11,244	1,288	12,532
48	66	0.30	16	4	599	176	557	10,880	1,332	12,212
54	59	0.30	16	5	674	203	557	15,666	1,434	17,100
60	53	0.30	18	5	749	221	626	17,537	1,596	19,133
66	48	0.30	18	6	823	248	626	23,913	1,698	25,611
72	44	0.30	18	6	898	265	626	25,171	1,789	26,960
78	41	0.30	18	7	973	288	626	31,944	1,887	33,831
84	38	0.30	18	7	1,048	311	626	35,521	1,985	37,507
90	35	0.30	18	8	1,122	337	626	41,963	2,085	44,048
96	33	0.30	18	8	1,197	355	626	44,497	2,178	46,675
102	31	0.30	18	9	1,272	382	626	54,102	2,280	56,381
108	29	0.30	18	9	1,346	400	626	56,254	2,372	58,627
120	27	0.30	18	10	1,496	427	626	71,986	2,549	74,535
132	24	0.30	18	11	1,645	490	626	86,857	2,761	89,619
144	22	0.30	18	12	1,795	540	626	101,910	2,961	104,872

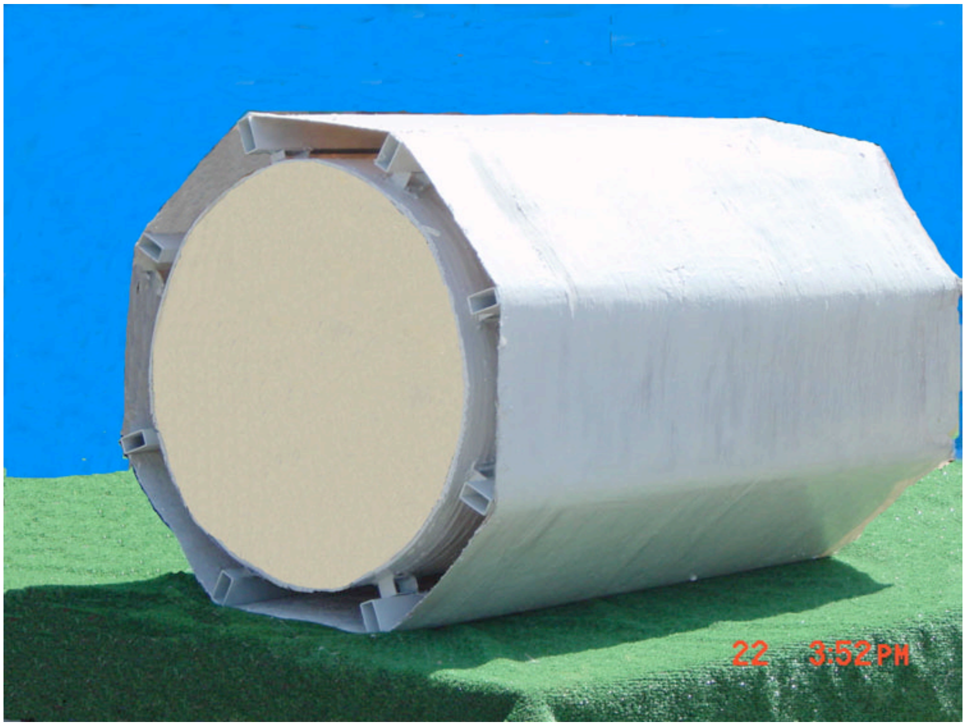

FIGURE 1. VIEW OF DOUBLE-WALL FIBERGLASS POLYGON PIPE

FIGURE 2. TENSILE TESTING INNER FIBERGLASS PIPE LAMINATE

FIGURE 3. BEGIN TESTING CONCRETE PIPE TO 9% DIA. DEFLECTION

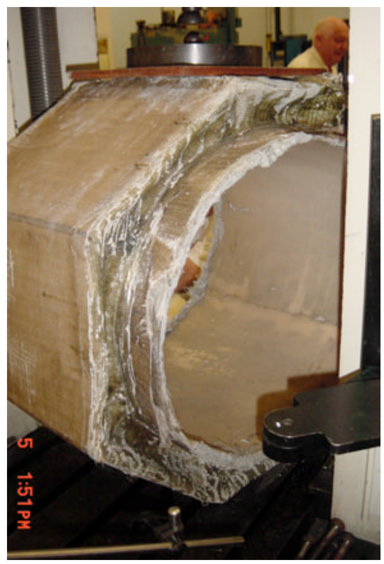

FIGURE 4. CONCRETE PIPE TESTED TO 9% DIAMETER DEFLECTION

FIGURE 5. CONCRETE PIPE AFTER 9% DIA. DEFLECTION TEST

FIGURE 6. VIEW OF CRACKED CONCRETE UPPER SIDE PIPE WALL

FIGURE 7. VIEW OF CRACKED CONCRETE PIPE SIDE WALL

FIGURE 8. VIEW OF INNER PIPE AND CONCRETE WALL SECTION