

DESIGN AND PERFORMANCE GUIDE FOR NEW TECHNOLOGY IN IRRIGATION PIPE

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ABSTRACT

The state of our irrigation infrastructure is in a declining state of disrepair. Next generation materials and products are necessary to accommodate new demands for irrigation systems and meet long-term performance requirements. This paper will explain key features to be expected in the new irrigation and drainage technology. One of these features includes combining traditional pipe materials to form a composite pipe structure capable of exceeding the performance of single material products. This new technology is an intelligent design of steel reinforcement to control hoop stress and HDPE to create a corrosion barrier and attenuate transient pressure waves. Maintaining control of the transient pressure waves (or water hammer) related impulse load on the pipe, and associated irrigation system, reduces the initial system cost and extends the service life for the entire system. Test data that demonstrates the reduction in magnitude of these peak pressures as a result of this new technology will be presented.

Advancements in pipe jointing technology also utilizing a composite of materials will also be discussed. Additionally, potential failure modes of some pipe joints will be identified.

In summary, research data will be presented that demonstrates the attenuation of peak loads on pipe joint and provide design guidance for a new generation of irrigation pipe. Additionally, the paper will present design guidance and design life predictions for irrigation and drainage pipe. This paper will benefit owners and engineers looking to increase the irrigation industry requirements for future irrigation projects.

INTRODUCTION

In many parts of North America gravity flow and low pressure irrigation systems were installed in the late 1950's and early 1960's. Many of these systems are nearing the end of their useful design life. Additionally, water is becoming a more precious commodity. Therefore engineers are being asked to choose a pipe system to service the agricultural irrigation system for the next century. This paper reports on several studies that were conducted to determine the service life and performance characteristics of a low head irrigation pipe intended to meet these long term design challenges.

Contech Construction Products has developed a pipe system which is designed to service gravity flow and low head pressure agricultural irrigation applications. This product

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called DuroMaxx is available in sizes ranging from 24-inches to 120-inches in diameter. This report explains testing that was conducted to determine performance characteristics and design life of this irrigation pipe.

This paper also describes the development of data to determine the pressure wave velocity for a new design for low head irrigation pipe. An example problem will demonstrate the expected surge pressure due to sudden change in velocity. Once the surge pressure is developed by the example problem, the impact of the surge pressure on the waterway wall and pipe joint will be analyzed.

BACKGROUND

The DuroMaxx pipe wall is a composite design of steel reinforcing ribs that are fully encased within the HDB rated HDPE profile. The steel reinforcing ribs provide the structural strength to resist the compressive or thrust loads from the backfill material. Additionally the steel ribs resist hoop or circumferential expansion due to internal hydrostatic pressure. The HDPE material forms the waterway wall and a protective barrier for the steel reinforcing ribs. Figure 1 below illustrates a cross section of the pipe wall.

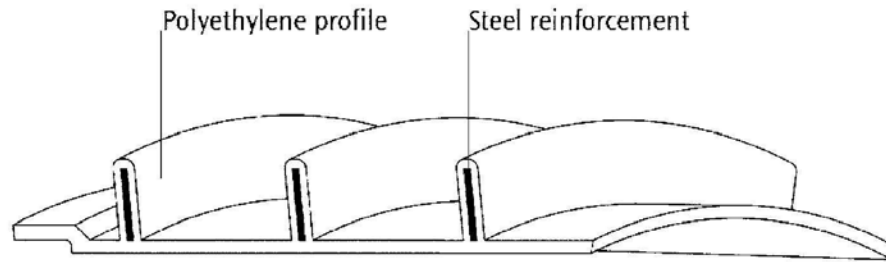


Figure 1. Cross Section of Pipe Wall

In addition to the use of steel reinforcing ribs, the bell and spigot of the pipe (i.e. pipe joint) is a composite that uses steel reinforcing bands. These steel reinforcing bands control dimensional tolerances of the joint when subjected to internal pressure. Figure 2 below illustrates a cross section drawing of the composite pipe joint.

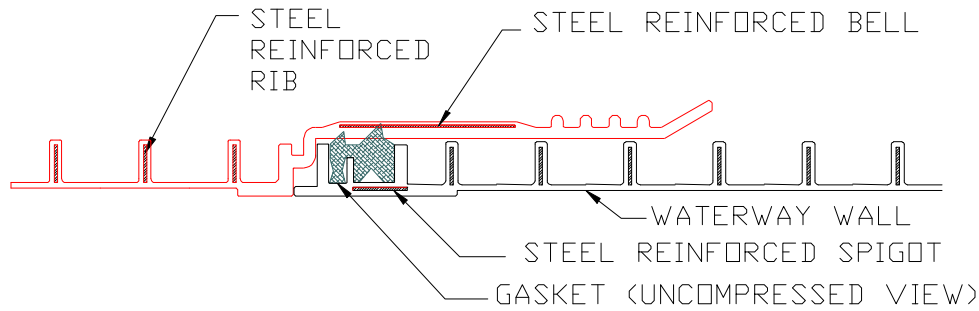


Figure 2. Pipe Joint Cross Section Drawing

The modulus of elasticity of HDPE is relatively low compared to other pipe materials. A typical short term modulus of elasticity for HDPE ranges from 110,000 psi and 150,000 psi. The modulus of elasticity of the steel reinforcement is approximately 29,500,000 psi. Both of these are traditional pipe materials; however the composite use of these materials is somewhat unique. Therefore it was necessary to conduct tests to determine the pressure wave velocity, long term performance and design life of this composite pipe system. Specific areas of interest for this pipe system study includes the impact the steel has on pressure wave velocity, the waterway wall response to pressure wave loading, and the bell and spigot response to the hydraulic loading.

Composite System's Impact on Pressure Wave Velocity

The HDPE's component of the pipe wall composite has a relatively low modulus of elasticity which has the effect of reducing the pressure wave velocity. The steel portion of the composite has a much higher modulus of elasticity which has the effect of increasing the transient pressure wave velocity. In order to determine the composite effect of these two materials on the pressure wave velocity, it was necessary to perform testing to measure the actual pressure wave velocity. Therefore full scale testing was performed to measure the pressure wave velocity of the composite pipe wall system.

To ensure the irrigation system is properly designed to handle the static pressure plus the transient pressure wave, it was necessary to determine the total pressure the system is likely to experience. The maximum transient surge pressure (also referred to as water hammer) is short-term pressure directly related to the pressure wave velocity within the pipe and is described by Equation one below.

$$P_s = \pm \frac{a * \Delta V}{2.31 * g}$$

P_s = Transient Surge Pressure (psi)

a = Wave Velocity (ft / sec)

ΔV = Sudden Velocity Change (ft / sec)

g = Gravitational Accerlation (32.2 ft / sec²)

(Equation 1)

There are a number of causes for pressure in an irrigation pipe system which may be experienced during normal operation. Terms critical to describing the types of pressures within the irrigation pipe system and used within this report are defined as follows:

1. Static Pressure (Long Term Pressure) – Maximum sustained long-term static pressure of a pipe system without consideration or inclusion of the transient surge pressures.
2. Working Pressure – Maximum allowable pressure within the system. The maximum working pressure is composed of the magnitude of the pressure rating plus maximum surge pressure.
3. Short-Term Pressure – Maximum short-term pressure is the sum of the magnitude of the static pressure plus the magnitude of the maximum transient surge pressure.
4. Transient Surge Pressure (Surge Pressure) – Short-term pressure as a result of a sudden change in velocity. This surge pressure does not include static pressure.

METHODOLOGY

Testing for the water hammer (or pressure wave velocity) and the pipe wall response to internal pressure were conducted on 24" diameter DuroMaxx pipe. Test results were used to verify analytical models. Analytical projections were then used to project larger diameter pipe response.

Pressure Wave Velocity

Testing was implemented to measure the pressure wave velocity. Figure 3 below is a schematic diagram illustrating the test fixture layout. Illustrated in Figure 3 is a five foot section of pipe orientated vertically, a 90 degree elbow and approximately 47 feet of pipe horizontally, which is instrumented and filled with water. The test fixture includes a steel pole orientated vertically, which guides a falling weight to the impact plate.

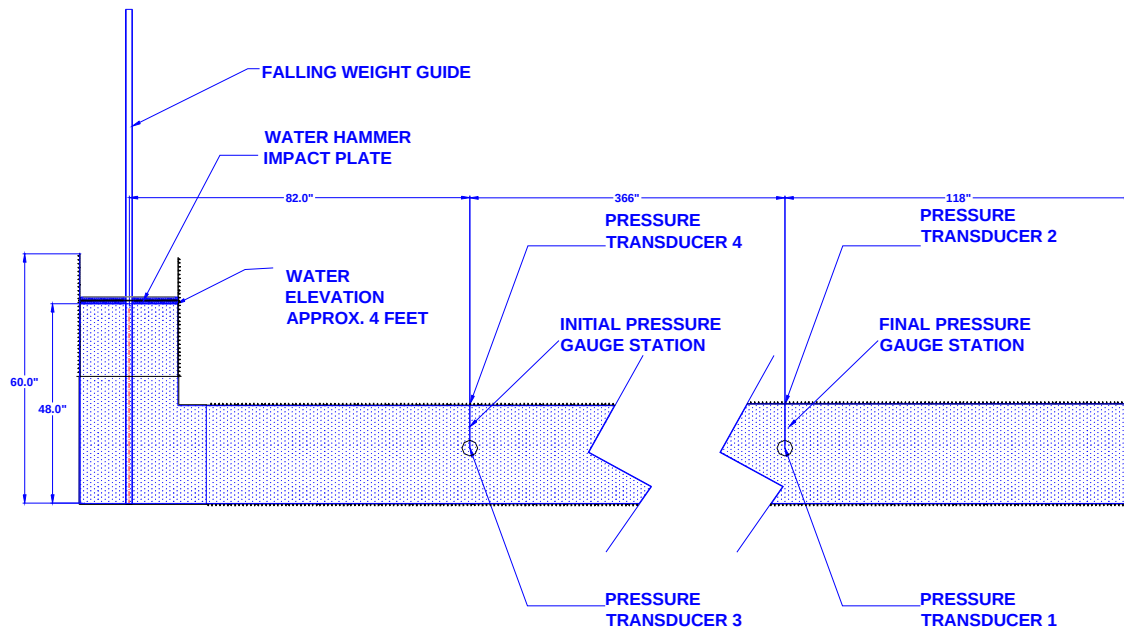


Figure 3. Schematic Diagram of Test Fixture

15 different tests were conducted by dropping specific weights onto a water hammer impact plate located at the water surface, which introduces a pressure wave into the system. This falling weight was dropped from five different elevations ranging from one foot to five feet in one foot increments. Additionally, the three different weights (i.e. 45 lbs, 65 lbs, and 85 lbs.) were dropped from each elevation. This variation in drop heights and weights generated a variety of pressure wave magnitudes.

Data collected from each of the 15 tests were measured by pressure transducers and captured by a data acquisition module. Pressure transducers were mounted at 4 locations along the length of the pipe. Two pressure transducers were mounted horizontally and two others were mounted vertically.

The initial pressure gauge station was located approximately 82" from the center of the elbow. At the initial gauge station a pressure transducer was mounted horizontally (gauge no. 3) and another was mounted vertically (gauge no. 4). Figure 4 illustrates the initial gauge station and pressure transducer no. 4, which was mounted vertically in the crown of the pipe. The final pressure gauge station was located 30.5 feet from the initial gauge station. At the final gauge station a pressure transducer was mounted horizontally (gauge no. 1) and a second was mounted vertically (gauge no. 2).

Pressure measurements were captured at a rate of 1,000 measurements per second. Separation distance between the pressure transducers and ends of the test segments were designed to minimize echo or "noise" from the translation of the pressure wave from end to end of the test fixture.



Figure 4. Pressure Transducer No. 4

Instrumentation for Data Acquisition. The data acquisition system and instrumentation was specified specifically for this project and is summarized as follows:

1. 1-MHz, 16-Bit, Data Acquisition Module
2. 4-solid state pressure transducers, max 30 psi, 0.25% accuracy
3. Omega linear 24 volt power supply
4. DaqView Software
5. Dell M20, 2 MHz, Laptop computer

The accuracy of the pressure transducers were checked with a known elevation or ‘head’ of water over the pressure transducer. Additionally, all instruments were certified as accurate by the supplier (Omega Engineering).

Pressure Wave Generation and Data Analysis. The pressure wave was generated by dropping a weight onto an impact plate on the water surface. The outside diameter of the impact plate was slightly less than the inside diameter of the DuroMaxx pipe. A rubber seal was placed between the edge of the impact plate and pipe waterway wall, which improved the energy transfer to generate the pressure wave. Prior to dropping the weight, the data acquisition began, which stored the data in an ASC II file. The ASC II data file

was imported into an Excel spreadsheet. Figure 5 illustrates a typical complete data set for one test. It should be noted that Figure 5 illustrates the different initial pressures of each gauge.

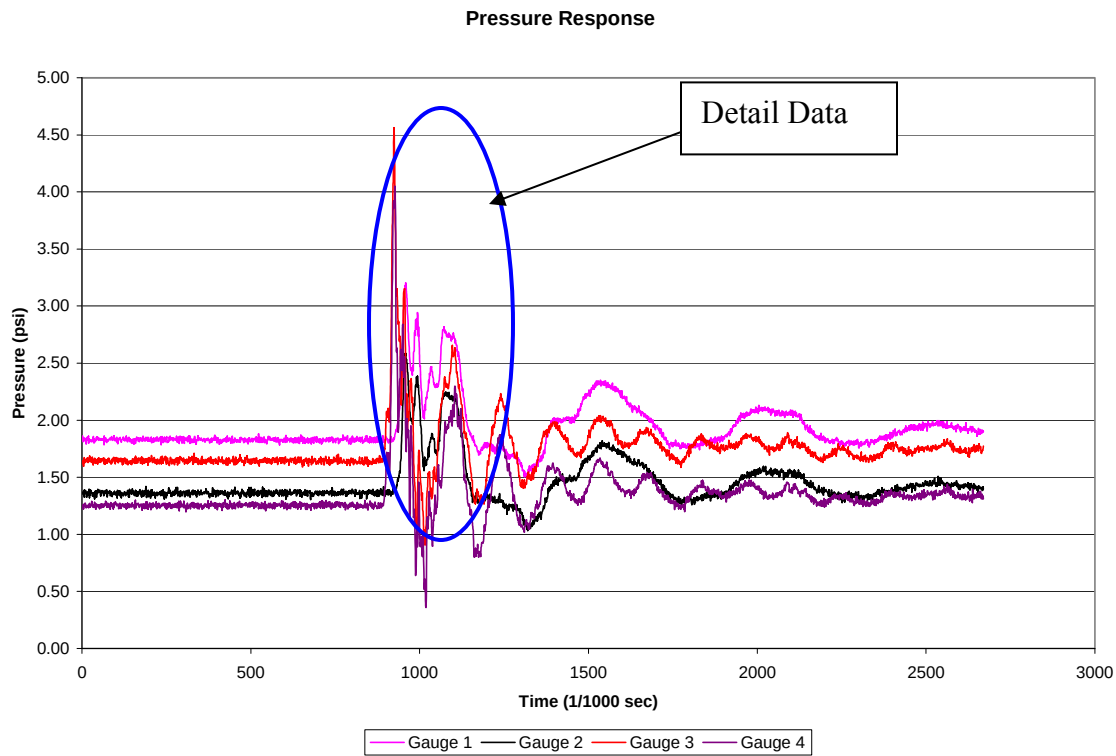


Figure 5. Plot of Typical Complete Data Set

Figure 5 includes data for multiple translations of the pressure wave within the 47 foot horizontal section of the test pipe. Once the data was collected, a plot of detailed data associated with the first pressure wave measurement for the initial and final pressure transducers was plotted. Identified in the Figure 5 plot is a region of detailed data, which is the detail data plotted in Figure 6. It is noted that each pressure transducer is located at different elevations. Therefore, the data has been shifted to normalize initial pressure for each pressure transducer. Once the initial pressure has been shifted and normalized, the detailed data was graphed as illustrated in Figure 6 below.

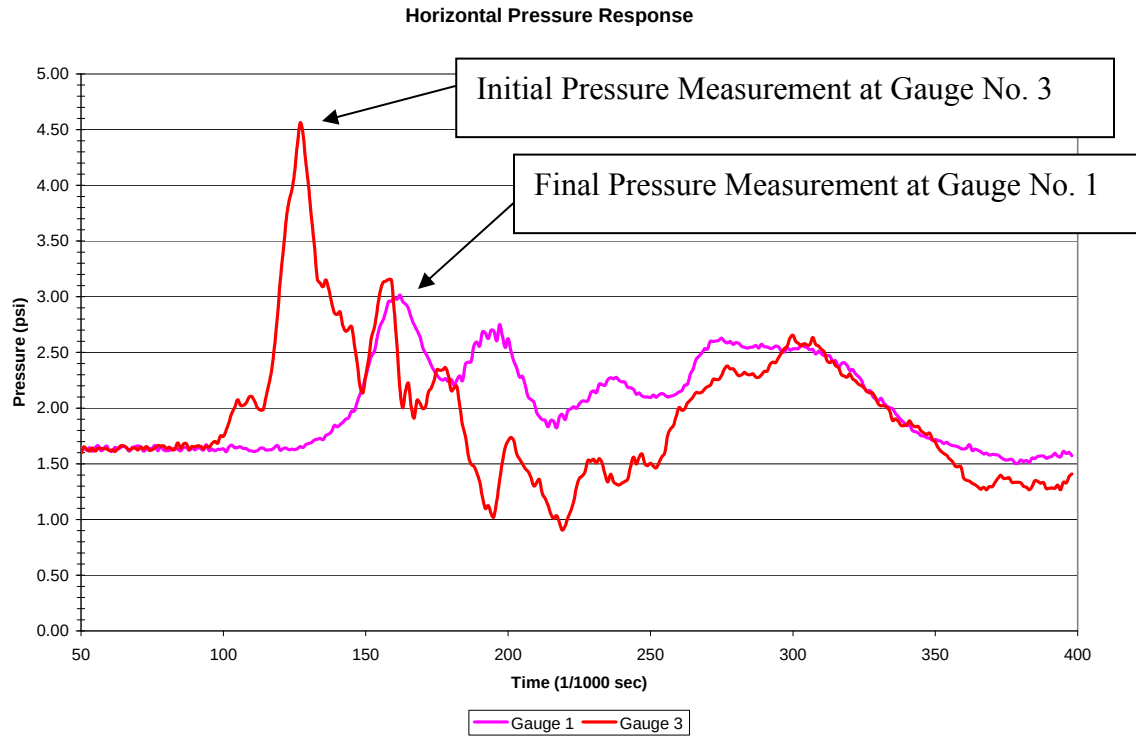


Figure 6. Plot of Typical Detailed Data Set

TEST RESULTS

Test results for the pressure wave velocity and the pipe waterway response to pressure are presented below.

Pressure Wave Velocity

Pressure and time data was captured during the testing. The distance between the initial pressure gauge station and the final pressure gauge station was 30.5 feet. The time between the peak pressure at the initial pressure gauge station and the final pressure gauge station was measured to the nearest 1/1000 second with the data acquisition system. The average velocity of the pressure wave was calculated using Eq (2) below.

$$V = \frac{\Delta D}{\Delta t}$$

Where :

$\Delta D \equiv$ Change In Distance (ft)

$\Delta t \equiv$ Change In Time (sec)

(Equation 2)

Based on the test data, the average measured velocity of the pressure wave is 919 ft/sec. Individual measurements for each of the 15 tests are shown in Table One below:

Table 1. Measured Velocity

Case #	Relative Time @ Gauge 3 (sec/1000)	Relative Time @ Gauge 1 (sec/1000)	Change in Time (sec/1000)	Distance between Gauges (feet)	Avg. Velocity (ft/sec)
1	198	231	33	30.5	924.2
2	71	104	33	30.5	924.2
3	127	162	35	30.5	871.4
4	71	107	36	30.5	847.2
5	66	98	32	30.5	953.1
6	128	160	32	30.5	953.1
7	217	251	34	30.5	897.1
8	134	167	33	30.5	924.2
9	86	118	32	30.5	953.1
10	60	93	33	30.5	924.2
11	130	161	31	30.5	983.9
12	63	97	34	30.5	897.1
13	107	139	32	30.5	953.1
14	150	182	32	30.5	953.1
5	54	91	37	30.5	824.3

The wave pressure is a function of the wave velocity as shown in Eq (1). Additionally, the wave velocity is a function of the stiffness of the pipe environment. Further the modulus of elasticity for the waterway wall influences the pipe's response during a pressure wave event. A comparison of wave velocity for different pipe materials is shown in Table Two below.

Table 2. Comparison of Transient Wave Velocities

Pipe Type	Wave Velocity (ft/sec)	Modulus of elasticity for Waterway Wall (psi)
Solid wall HDPE (DR 17)	836	150,000
DuroMaxx	919⁽¹⁾	150,000⁽²⁾
PVC DR 18	1,303	400,000
Ductile Iron (CL 50)	3,981	24,000,000

Notes:

1. The wave velocity is slightly higher than a purely HDPE system as a result of the steel reinforcing ribs.
2. Modulus of elasticity does not include influence of steel reinforcement.

A comparison of the various pipe materials and the associated pressure wave velocity indicates the wave velocity of DuroMaxx is comparable to that of solid wall HDPE.

Furthermore, it is concluded that the HDPE portion of the waterway wall dominates the DuroMaxx response to internal transient pressure waves.

Predicting Wave Velocity for Larger Diameters of DuroMaxx. Testing performed in this study determined the pressure wave velocity for 24" DuroMaxx. DuroMaxx is presently available for sizes up to 60" in diameter. Ultimately DuroMaxx will be available up to 120 inch in diameter. This study addresses sizes up to 60-inch in diameter.

The velocity of the pressure wave is a function of the hoop stiffness of the pipe. The relationship between the pressure wave velocities may be expressed as shown in Eq (3).

$$a = \frac{4660}{\sqrt{1 + \left[K_{BULK} * K_s * \left(\frac{\left(\frac{D_{HDPE}}{t_{HDPE}} \right) - 2}{E_d} \right) \right]}}$$

Where :

a = Wave Velocity (ft / sec)

K_{BULK} = Bulk Modulus (water = 300,000 psi)

E_d = Instantaneous Modulus of HDPE (150,000 psi)

D_{HDPE} = Outside Diameter of Waterway Wall (in)

t_{HDPE} = Thickness of HDPE (in)

K_s = Steel Stiffness Influence Coefficient

(Equation 3)

Testing described in this report determined the velocity of a transient surge pressure wave for 24" diameter DuroMaxx pipe. Since all variables described in Eq (3) are known except the Steel Stiffness Influence Coefficient (K_s), it is necessary to algebraically solve Eq (3) for the steel stiffness influence coefficient. It is noted the steel stiffness influence coefficient was developed specifically for this analysis. Eq (4) below reflects the steel stiffness influence coefficient as a function of known variables and may be solved for the steel stiffness influence coefficient (K_s).

$$K_s = \left(\left(\frac{4660}{a} \right)^2 - 1 \right) * \left(\frac{E_d}{\left(\frac{D_{HDPE}}{t_{HDPE}} \right) - 2} \right) * \left(\frac{1}{K_{BULK}} \right)$$

Where :

a = Wave Velocity = 919 ft / sec

K_{BULK} = Bulk Modulus = 300,000 psi

E_d = Instantaneous Modulus of HDPE (150,000 psi)

D_{HDPE} = Outside Diameter of Waterway Wall = 23.8 in

t_{HDPE} = Thickness of HDPE = 0.068 in

K_s = Steel Stiffness Influence Coefficient

(Equation 4)

Substituting known values into Eq (4) and solving as follows:

$$K_s = \left(\left(\frac{4660^2}{a} \right) - 1 \right) * \left(\frac{150,000}{\left(\frac{23.8}{0.068} \right) - 2} \right) * \left(\frac{1}{300,000} \right) = 0.0358$$

Therefore:

$K_s \equiv$ Steel Stiffness Influence Coefficient = 0.0358.

Since the wave velocity increases with higher pipe stiffness and 24" diameter pipe has the greatest stiffness of the DuroMaxx product offering, it is reasonable and conservative to use the 24" steel stiffness influence coefficient ($K_s=0.0358$) for all pipe diameters. Using Eq (3), the steel stiffness influence coefficient and the dimensions of the remaining diameters of DuroMaxx, the pressure wave velocities may be calculated. Based on the foregoing, the pressure wave velocity for the remaining diameters of DuroMaxx is shown in Table 3 below.

Table 3. Pressure Wave Velocity for DuroMaxx

Nominal Diameter (in)	Wave Velocity (ft/sec)
24	918.7
30	908.2
36	831.3
42	771.1
48	898.9
54	849.0
60	806.5

As shown in the Table Three the maximum wave velocity is 919 ft/sec and the minimum wave velocity is 807 ft/sec.

Dissipation of Wave Energy. Another outcome of the testing and analysis was that the pressure wave is dissipated relatively quickly within the DuroMaxx pipe. Tests show that the dissipation of the pressure wave varied from 20% to 41% of its magnitude over a distance of 30.5 feet. Detailed discussions regarding this data are outside of the scope of this paper, but are worthy of noting.

Design Guide for DuroMaxx in Irrigation Applications. A critical part of this study is to determine the appropriate operating parameters for the use of DuroMaxx in irrigation applications. Based on the pressure wave velocity test results, the HDPE material dominates the DuroMaxx response to transient pressure waves. The HDPE response to the pressure wave reduces the wave velocity thereby reducing the transient pressure wave magnitude. Specifically the viscoelastic characteristics of polyethylene enable DuroMaxx to safely withstand instantaneously applied transient surge pressures. Strain associated with these momentary pressure loads are proportional to the elastic response of the HDPE, which is relieved upon removal of the pressure load. The temporary elastic strain does not damage the polyethylene material and does not adversely affect the pipe's long-term strength provided the magnitude of the short term strain is within the short term strain capacity of the material.

EXAMPLE ANALYSIS

This section of the report runs through an example analysis and evaluates effect of projected pressures on the pipe waterway wall and pipe joint. Observations regarding the impact of the projected pressures are noted as well as distinguishing characteristics between the DuroMaxx pipe design and other non-composite pipe designs are noted.

Solve Example Problem

The following is an example analysis to determine the suitability of DuroMaxx.

Given:

24" DuroMaxx

Maximum Long term Static Pressure: 15 psi

Fluid Velocity: 2 ft/sec.

Maximum Working Pressure for 24" DuroMaxx = 45 psi

Determining the Transient Surge Pressure with Eq (1) shown below:

$$P_s = \pm \frac{a * \Delta V}{2.31 * g}$$

P_s = Transient Surge Pressure (psi)

a = Wave Velocity (919 ft/sec)

ΔV = Sudden Velocity Change (2 ft/sec)

g = Gravitational Acceleration (32.2 ft/sec²)

(Equation 1)

Solving Eq (1):

$$P_s = \pm \frac{a * \Delta V}{2.31 * g} = \frac{(919) * (2)}{(2.31) * (32.2)} = 25 \text{ psi}$$

Determining the Maximum Short Term Pressure for this application:

Maximum Short Term Pressure = Long term pressure + Surge pressure

Maximum short term pressure = 15 psi + 25 psi = 40 psi

Working Pressure Check:

Working pressure $\leq$ Maximum Short Term Pressure

45 psi $\geq$ 40 psi (therefore application ok)

Determining the Pipe Joint Response to 40 psi pressure.

As previously mentioned the DuroMaxx pipe joint is a composite pipe joint, which includes steel reinforcing in the bell and spigot. Pipe joints for the irrigation industry must maintain water tightness for long durations of internal pressure. ASTM D3212 describes a typical methodology for testing thermoplastic pipe joints. Pipe joints meeting this requirement are regularly promoted in the agricultural irrigation industry. This pipe joint test is a 10 minute laboratory test. In the case of thermoplastic pipe joints, the bell and/or spigot may creep over time when subjected to internal pressure or gasket compression load associated with the pipe joint assembly. Figure 7 below illustrates a non-reinforced HDPE pipe joint design, which may be subject to creep. Some manufacturers of HDPE pipe are beginning to reinforce the bell of the pipe but few are actually reinforcing the bell and spigot.

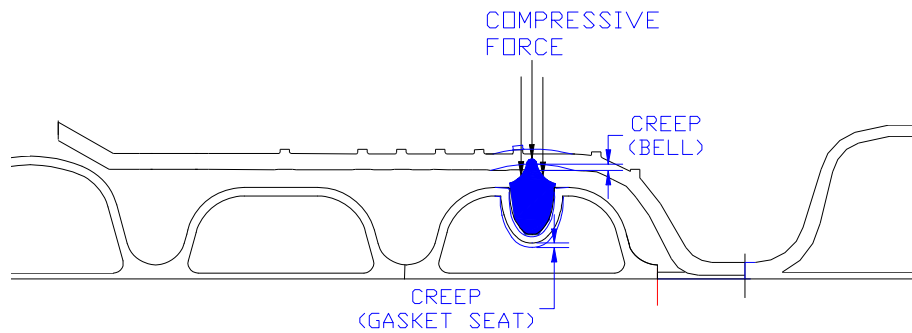


Figure 7. Non-reinforced HDPE Pipe Joint

A comparison between an unreinforced and reinforced bells and spigots are shown in Table 4 below. These values were derived analytically based on traditional strength of materials analysis. Assumptions for the analysis are shown as follows:

- Internal pressure = 15 psi
- Bell Inside Diameter = 25 inches
- Spigot Outside Diameter = 24.5 inches
- HDPE Bell Thickness = 0.2 inch
- HDPE Spigot Thickness
- Steel Reinforcement thickness = 0.04 inch
- Modulus of steel after one year service = 29,500,000 psi
- Modulus of HDPE after 10 minutes = 89,000 psi
- Modulus of HDPE after 1 year = 36,300 psi

Table 4. Performance comparison for reinforced and unreinforced pipe Joints

Bell inside diameter		
Time	Inside Diameter HDPE Bell (non reinforced)	Insider Diameter HDPE Bell (steel reinforced)
Initial bell inside diameter	25"	25"
After 10 minutes	25.26	25.004
After 1 year	25.65	25.004
Spigot outside diameter		
Time	Outside Diameter HDPE spigot (non reinforced)	Outside Diameter HDPE spigot (steel reinforced)
Initial spigot outside diameter	24.5"	24.5"
After 10 minutes	24.37	24.499
After 1 year	24.19	24.499

As shown above unrestrained HDPE goes through substantial deformation when subjected to constant internal hydraulic pressure for long periods of time. This change results in a loss of compression in the gasket and may result in a loss in the watertight seal at the joint.

In the case of the example where the DuroMaxx reinforced joint is subjected to 40 psi the bell inside diameter will increase by 0.01 inch to a new inside diameter of 25.01 inches. Where as the spigot will decrease in diameter by approximately 0.005 inch to a shortened outside diameter of 24.949 inch. These changes in diameter are well within the tolerance of the pipe joint and a watertight seal will be maintained.

Determining the Pipe Waterway Wall Response to 40 psi Pressure.

A second series of testing conducted during this study was to determine the pipe wall response as a function of the internal pressure. Of particular interest is the waterway wall response and required wall thickness to ensure a long term design life. Maximum allowable strain levels are well established for HDPE material. Therefore this portion of the study was conducted to ensure the wall thickness exceeded the minimum allowable.

This section describes the pipe wall response to internal pressure. As shown in figure 8 below the pipe wall will deflect when subjected to internal pressure. The pipe wall resists deformation through a combination of bending and membrane resistance. The waterway wall also resists shear stress and hoop stress. However steel within the rib reduces the magnitude of hoop stress in the waterway wall. To determine the magnitude of stress within the pipe waterway wall the deflection of the pipe wall was measured as a function of pressure. The measurement was made at the midpoint between the reinforcing ribs (as shown in Figure 8).

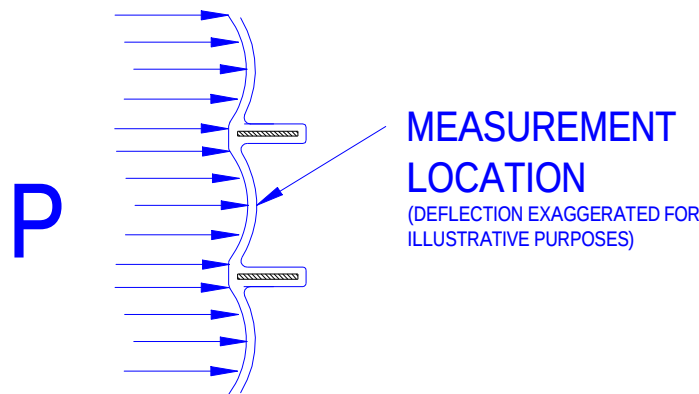


Figure 8. Pipe Wall Deflection

Pressure testing was performed on 24" diameter pipe with both ends plugged and subjected to internal water pressure. Once the pipe was subjected to internal pressure the response of the waterway wall was measured. Deflection measurements were measured

by mounting a displacement transducer on the pipe. Additionally a pressure transducer was mounted in the pressure feed line. Pressure and displacement data was captured at rate of 1 measurement per second. The pressure was stepped up and displacement was measured at the acquisition rate of 1 measurement per second. Testing was performed above 30 psi for investigative proposes only. It is noted that the pressure transducer was rated for 30 psi. Therefore pressure measurements above 30 psi do not respond linearly to voltage and are not considered accurate. These values (above 30 psi) are shown for illustrative purposes only.

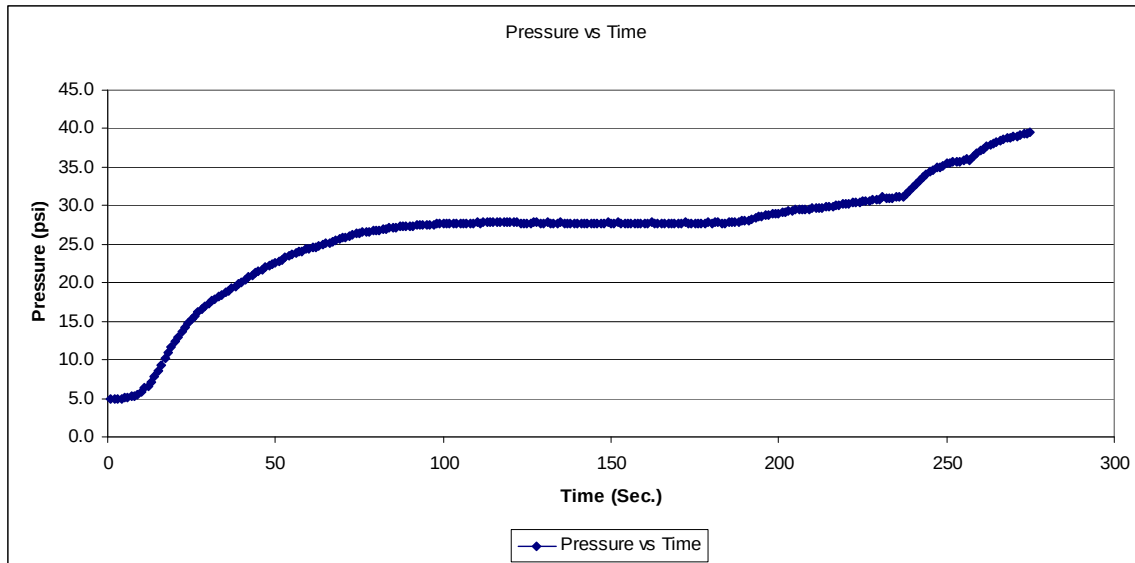


Figure 9. Pressure Application as a Function of Time

Instrumentation for Data Acquisition. The data acquisition system and instrumentation was specified specifically for this project and is summarized as follows:

1. 1-MHz, 16-Bit, Data Acquisition Module
2. 1-solid state pressure transducers, max 30 psi, 0.25% accuracy
3. 1- Linear Displacement Transducer, max 1 inch, 0.2% accuracy
4. Omega linear 24 volt power supply
5. DaqView Software
6. Dell M20, 2 MHz, Laptop computer

The accuracy of the pressure transducer and displacement transducer were checked with known elevation or ‘head’ of water over the pressure transducer and a known displacement. Additionally, all instruments were certified as accurate by the supplier (Omega Engineering).

Waterway Wall Displacement vs. Pressure Data Analysis. The displacement of the waterway wall versus internal pressure was measured and is shown in Figure 10 below. The pipe was mounted in test fixture and subjected to internal pressure. Displacement of the waterway wall and internal pressure were measured with a data acquisitions system

and stored the data in an excel spreadsheet. As shown in results graphed in Figure 10, at internal pressures of approximately 40 psi the waterway displacement of 0.054" was measured. This displacement represents a total strain of 3.2%, which is well within the allowable long term strain limit of 6.5%

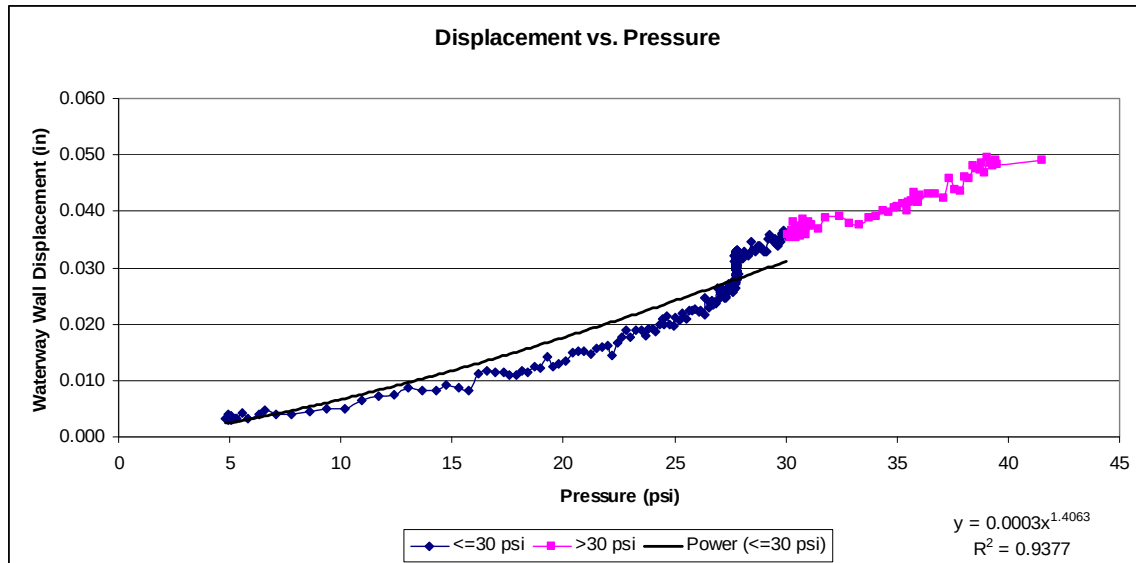
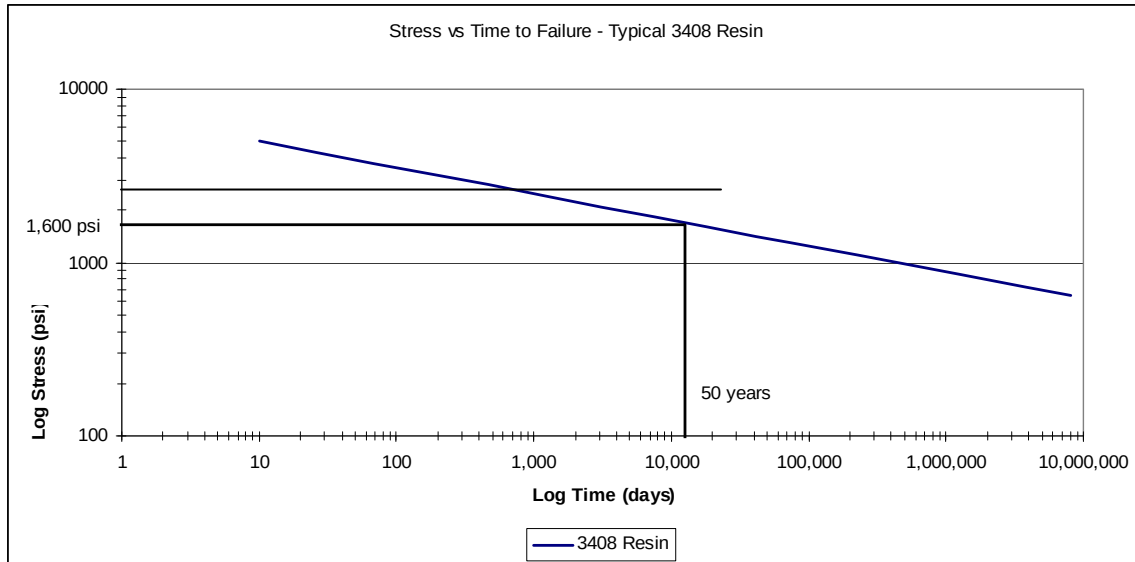


Figure 10. Waterway wall displacement vs. pressure

Response of Waterway Wall Related to Design Life. The long-term pressure rating for DuroMaxx is 15 psi of constant head pressure. As shown in Figure 10 this pressure corresponds to a waterway wall displacement of approximately 0.014 inch. This level of displacement represents a total strain at the midpoint between the ribs of 1.6% or a stress level of 360 psi. It is noted this HDPE has a design life of 50 years at a 1,600 psi stress level.

Figure 11 below illustrates a typical plot of stress vs. time to failure for HDPE. As can be seen at stress levels less than 1,000 psi the design life of the system are well over 100-years. It should be noted that this design life assumes there is no chemical failure of the HDPE such as antioxidant depletion. With that said the 50-year design life is well established for this class of HDPE and it is reasonable to expect the design life of the system to substantially exceed the recognized 50-year life. This design life assumption is especially true considering the service stress is approximately 22.5% of the design stress for 50 year service life.



Insert Figure 11. 3408 resin stress vs. time to failure

SUMMARY

DuroMaxx pipe is designed for the low pressure (15 psi and below) and gravity flow irrigation systems. 45 psi short term pressures due to transient pressure waves plus constant operating head pressure are within the design limits of the product. These allowable pressure ranges are a result of the pipe wall construction, which is a composite of two materials (Steel & HDPE) and the use of high stress capacity HDPE.

Due to the composite nature of the pipe wall it was necessary to perform full scale testing to determine the influence of steel on the pressure wave velocity. Testing on the pipe was performed and direct measurements of pressure wave velocities were made. Testing determined an average wave velocity of 919 ft/sec for the 15 replicates of testing performed. It was observed that the dissipation of the pressure wave ranges from 20% to 40% over 30.5 feet of pipe, depending upon the magnitude of the pressure wave.

Composite pipe joints have demonstrated the pipe design's ability to withstand long-term internal hydraulic pressure without experiencing a loss of sealing capacity. This loss of sealing capacity is demonstrated in analytical calculations comparing reinforced and non-reinforced HDPE pipe joint.

Testing on the waterway wall as a function of pressure indicates that strain levels 1.6% at the midpoint between the pipe ribs. These strain levels are well within in HDPE material's 6.5% long term strain capacity.

CONCLUSION

This study demonstrates that the HDPE constituent of the pipe dominates the pipe's response to transient pressure waves. For the 15 different measurements of pressure wave tests, the average velocity of pressure wave within DuroMaxx is 919 ft/sec. This pressure wave velocity is comparable to that of a HDPE pipe.

Pipe joints are capable of withstanding long term gasket compression and associated water tightness at 15 psi. Additionally the joint design is suitable short term pressure spikes of 45 psi without loss of sealing capacity.

The pipe's waterway wall is capable of withstanding long term internal pressure of 15 psi which represents 1.6% strain at the midpoint between the ribs, which is less than the maximum long term strain capacity of 6.5%.

The pipe's waterway wall is capable of withstanding short term internal pressure of 45 psi which represents 3.3% strain at the midpoint between the ribs, which is less than the maximum long term strain capacity of 6.5%.

A design life of greater than 50-years is reasonable for 15-psi constant head and intermittent peak pressures of 45 psi.