VOLUME II: SEWER PIPING SYSTEMS DESIGN



Municipal Technical Manual Series

FOURTH EDITION

Ring-Tite® & Enviro-Tite® Sewer Pipe & Fittings
Ultra-Rib®, Ultra-X2™ & Perma-Loc™ Profile Pipe & Fittings
PVC Manholes & Access Chambers
Vortex Flow™ Inserts for Corrosion & Odor Control
Inlet Control Devices
Lifesaver™ Manhole & Catch Basin Adjustment Units

IPEX by aliaxis

We Build Tough Products for Tough Environments®

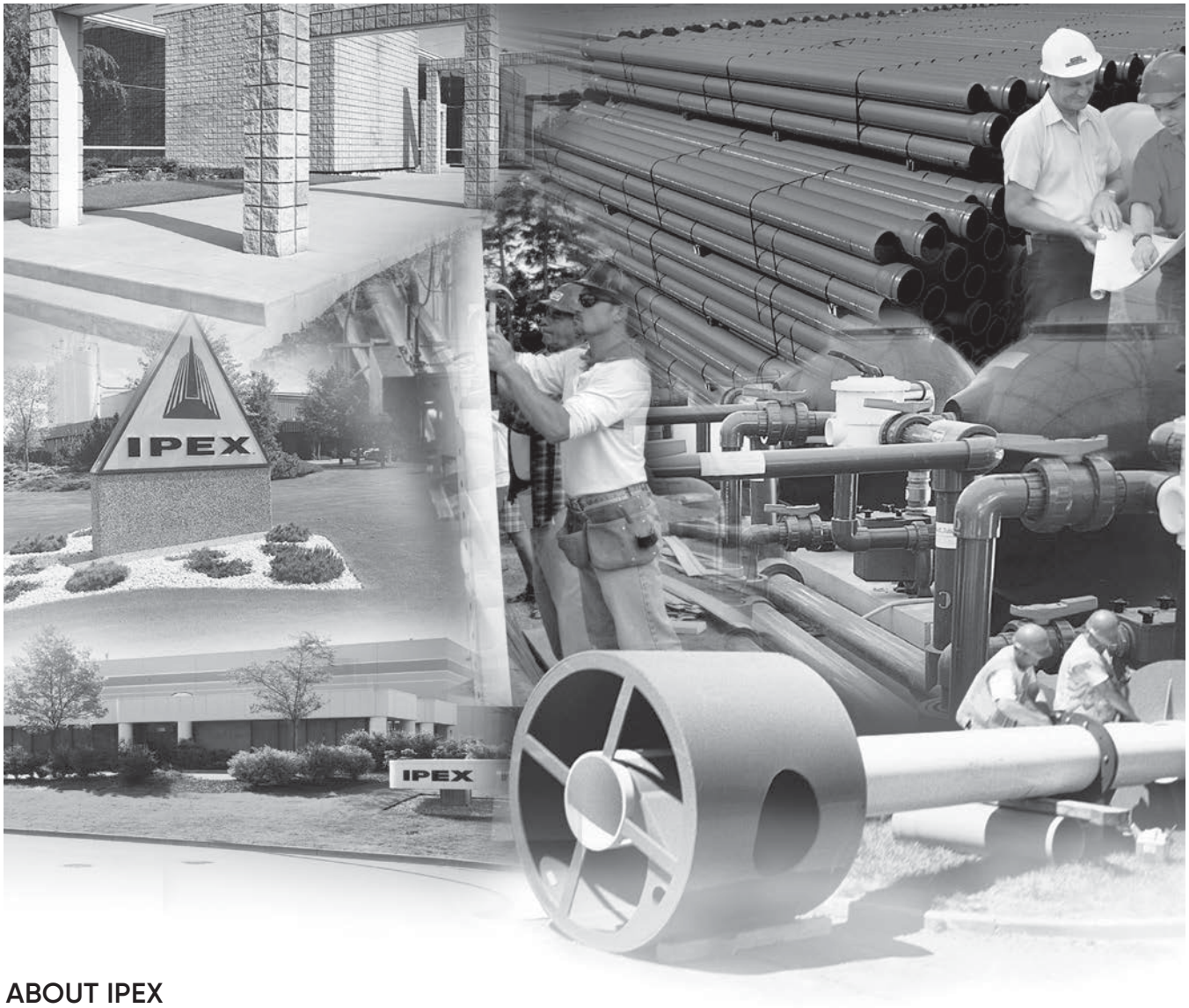
IPEX Sewer Piping Systems Design

Municipal Technical Manual Series

Vol. II, 4th Edition

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ABOUT IPEX

At IPEX, we have been manufacturing non-metallic pipe and fittings since 1951. We formulate our own compounds and maintain strict quality control during production. Our products are made available for customers thanks to a network of regional stocking locations throughout North America. We offer a wide variety of systems including complete lines of piping, fittings, valves and custom-fabricated items.

More importantly, we are committed to meeting our customers' needs. As a leader in the plastic piping industry, IPEX continually develops new products, modernizes manufacturing facilities and acquires innovative process technology. In addition, our staff take pride in their work, making available to customers their extensive thermoplastic knowledge and field experience. IPEX personnel are committed to improving the safety, reliability and performance of thermoplastic materials. We are involved in several standards committees and are members of and/or comply with the organizations listed on this page.

For specific details about any IPEX product, contact our customer service department (contact information is listed on the back cover).

ASTM MEMBER AWWA MEMBER MEMBER IAPD INTERNATIONAL ASSOCIATION OF PLASTICS DISTRIBUTORS FM NSF

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OVERVIEW

IPEX Inc. is one of the largest manufacturers of plastic piping systems in North America. IPEX manufactures piping systems for many different applications, including sewer and water supply, electrical and telecommunications systems, plumbing, industrial as well as radiant heating systems.

This design manual covers the technical aspects of designing sanitary and storm sewers and other gravity flow systems with PVC pipes and fittings. In addition, there is information on non-corroding PVC manholes, odor controlling drop structures as well as inlet control devices for stormwater systems.

The manual is organized into two sections:

Section 1 deals with specific products and includes detailed information on applications, dimensions and applicable standards for each system.

Section 2 deals with general design issues associated with flexible conduits and buried PVC pipe systems such as load and deflection calculations, hydraulics, chemical resistance and other key topics for designers. The latest research on each topic is outlined and properly referenced for further study.

This manual is designed for Engineers, Technologists and other municipal infrastructure professionals who require a deeper understanding of municipal piping systems than can be gleaned from the more general overview literature available from IPEX.

SECTION ONE: PRODUCT INFORMATION

INTRODUCTION

This section contains detailed information on the following products:

Ring-Tite® and **Enviro-Tite**® smooth wall PVC sewer pipe and fittings

PVC Profile Sewer pipe including **Ultra-Rib**®, **Ultra-X2**™ and **Perma-Loc**™

Corrosion proof manholes and access chambers

Vortex Flow™ Inserts for odor and corrosion control

Tempest™ Inlet Control Devices for stormwater management

Lifesaver™ Manhole and Catch Basin adjustment units

DESIGNING SEWERS WITH IPEX SYSTEMS

It is now possible to construct virtually every part of a sewer system using tough, non-corroding PVC pipes, fittings and appurtenances. While PVC pipes and fittings have been used for over 70 years for municipal applications, the technology has progressed to the point that a recycled PVC pipe is available with identical material properties and quality as virgin product. There are now PVC manholes and access chambers designed to eliminate infiltration and corrosion in key areas of the system. Specially designed vortex drop structures combat odour and corrosion and actually improve wastewater quality. For stormwater applications, custom designed inlet control devices help to conserve system capacity during storm events by allowing temporary surface storage of run off. Thermoplastics even help to extend the life of roads and concrete manholes and catchbasins – Lifesaver manhole and catchbasin adjustment units cushion the blow from wheel loads on manholes and catchbasins, while eliminating infiltration and undermining of the road bed.

With PVC pipe now available up to 1,500mm (60") in diameter, even trunk sewers can be built with corrosion proof PVC. Corroded and leaking sewer systems can be made a thing of the past – Specify PVC for all sewer systems up to 1,500mm (60").

[1] Hulsman, Nowack; "70 Years of Experience with PVC Pipe", Conference Paper, Plastic Pipes XII

RING-TITE® AND ENVIRO-TITE® PVC SEWER PIPE AND FITTINGS

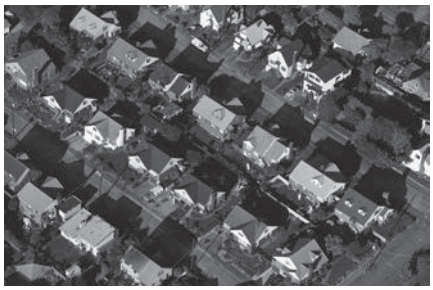
Ring-Tite and Enviro-Tite piping systems are SDR35 and SDR28 sewer pipes manufactured to demanding ASTM and CSA standards. The two products are identical except for Enviro-Tite having a minimum recycled material content of 50%. Both products have tight joints that can withstand well in excess of both the ASTM and CSA requirements.





Applications:

Gravity flow sanitary sewers, storm sewers, sewer laterals, industrial effluent lines.







Standards:

Ring-Tite Standards:

Certified to CSA B182.2

Certified to NQ 3624-130/135

Conforms to ASTM D3034 and ASTM F679

Enviro-Tite Standards:

Certified to CSA B182.2

Certified to NQ 3624-130/135

Conforms to ASTM F1760

Joint Tightness

Ring-Tite and Enviro-Tite pipe joints have been third party tested to withstand a 345 kPa (50 psi) hydrostatic pressure. Injection molded fittings have also been laboratory tested to withstand a 345 kPa (50 psi) pressure in an undeflected straight alignment. This does not mean that installations should be tested to these pressures in the field, as these pressures could damage manholes, laterals or other appurtenances that are not tested to the same standards as the pipe and fittings. We recommend the testing procedures outlined in our Installation Guide, which is available upon request or can be downloaded from ipexna.com.

Short Form Specifications

General

Main line sewers will be PVC SDR35 sewer pipe and shall be in compliance with ASTM D3040 or ASTM F1760 and third party certified to CSA B182.2. Sewer laterals will be PVC SDR35 or SDR28 sewer pipe sewer pipe and shall be third party certified by CSA as above.

Joints

Sealing gaskets must meet the requirements of ASTM D3034 or ASTM F1760, CSA B182.2. In addition, the pipe joints must be able to withstand a minimum hydrostatic pressure of 345 kPa (50 psi) without leakage.

Pipe Stiffness

The minimum ring stiffness shall be 320 kPa (46 psi) for SDR35 pipe and 625 kPa (90 psi) for SDR 28. This stiffness will be determined using the test methods prescribed by ASTM D3034 and ASTM F1760.

Fittings

Injection-molded gasketed PVC fittings shall meet the requirements of ASTM 3034 and ASTM F1336 and shall be certified to CSA B182.1 or CSA B182.2. Fabricated fittings must conform to ASTM F1336 and CSA B182.2

Dimensions:

Size Ranges

Ring-Tite (SDR35) 100mm – 1,500mm (4" – 60")

Enviro-Tite (SDR35) 100mm – 375mm (4" – 15")

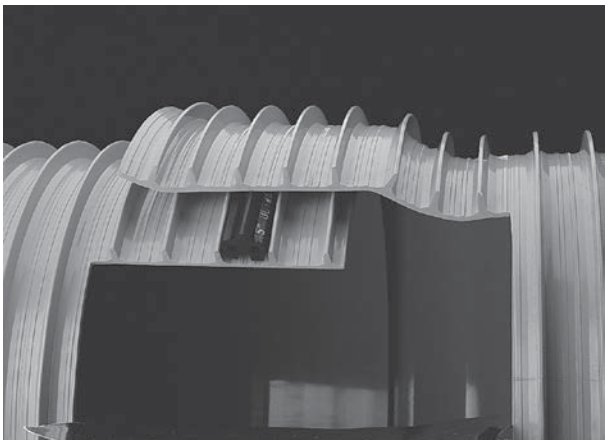
Ring-Tite		DR35						DR28					
Size		Avg. ID		Min. Wall Thickness		Avg. OD		Avg. ID		Min. Wall Thickness		Avg. OD	
in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm
4	100	3.97	100.94	0.12	3.06	4.21	107.06	3.91	99.42	0.15	3.82	4.21	107.06
5	135	5.32	135.08	0.16	4.09	5.64	143.26	5.24	133.02	0.20	5.12	5.64	143.26
6	150	5.92	150.29	0.18	4.55	6.28	159.39	5.83	148.01	0.22	5.69	6.28	159.39
8	200	7.92	201.16	0.24	6.10	8.40	213.36	-	-	-	-	-	-
10	250	9.90	251.46	0.30	7.62	10.50	266.70	-	-	-	-	-	-
12	300	11.79	299.36	0.36	9.07	12.50	317.50	-	-	-	-	-	-
15	375	14.43	366.42	0.44	11.10	15.30	388.62	-	-	-	-	-	-
18	450	17.63	447.87	0.53	13.57	18.70	475.01	-	-	-	-	-	-
21	525	20.79	527.99	0.63	16.00	22.05	559.99	-	-	-	-	-	-
24	600	23.39	594.00	0.71	18.00	24.80	630.00	-	-	-	-	-	-
27	675	26.36	669.42	0.80	20.29	27.95	710.00	-	-	-	-	-	-
30	750	30.17	766.36	0.91	23.22	32.00	812.80	-	-	-	-	-	-
36	900	36.11	917.22	1.09	27.79	38.30	972.80	-	-	-	-	-	-
42	1050	41.95	1065.72	1.27	32.29	44.50	1130.30	-	-	-	-	-	-
48	1200	47.89	1216.56	1.45	36.87	50.79	1290.30	-	-	-	-	-	-
54	1350	54.27	1378.49	1.64	41.77	57.55	1462.00	-	-	-	-	-	-
60	1500	58.08	1457.48	1.76	44.71	61.61	1564.90	-	-	-	-	-	-

Ring-Tite fittings are injection molded in most configurations up to 375mm (15") nominal diameter. Larger sizes are fabricated from sections of pipe.

Enviro-Tite		SDR35						SDR28						Schedule 40					
Size		Avg. ID		Min. Wall Thickness		Avg. OD		Avg. ID		Min. Wall Thickness		Avg. OD		Avg. ID		Min. Wall Thickness		Avg. OD	
in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm
4	100	3.97	100.94	0.121	3.06	4.215	107.06	3.91	99.42	0.150	3.82	4.215	107.06	3.99	101.34	0.237	6.02	4.500	114.30
5	135	-	-	-	-	-	-	5.21	133.02	0.201	5.12	5.640	143.26	-	-	-	-	-	-
6	150	5.89	150.29	0.179	4.55	6.275	159.39	5.80	148.01	0.224	5.69	6.277	159.39	-	-	-	-	-	-
8	200	7.89	201.16	0.240	6.10	8.400	213.36	-	-	-	-	-	-	-	-	-	-	-	-
10	250	9.86	251.46	0.300	7.62	10.500	266.70	-	-	-	-	-	-	-	-	-	-	-	-
12	300	11.74	299.36	0.357	9.07	12.500	317.50	-	-	-	-	-	-	-	-	-	-	-	-
15	375	14.37	366.42	0.437	11.10	15.300	388.62	-	-	-	-	-	-	-	-	-	-	-	-

IPEX ULTRA-RIB® PVC PROFILE PIPE AND FITTINGS

Profile wall pipes are newer designs than standard smooth wall pipe. The outside wall of the pipe is modified with concentric ribs that increase the stiffness of the ring cross section. Ultra-Rib is manufactured with an open profile. This means that the pipe is extruded as a smooth wall pipe, then special molds form concentric ribs into the outside wall of the pipe.





Applications:

Sanitary and Storm sewers, Industrial lines.







Standards:

IPEX Profile Pipe and Fittings

Certified to CSA B182.4

Certified to BNQ 3624-135

Conforms to ASTM F794

Conforms to AASHTO M304

Pipe Stiffness

IPEX Ultra-Rib is manufactured with a minimum 320 kPa (46 psi) ring stiffness to comply with ASTM and CSA standards.

Joint Tightness

IPEX Ultra-Rib profile pipe joints can easily withstand a 50 psi hydrostatic pressure. This is important as most jurisdictions require that any sewer pipe laid in close proximity (ie: less than 2.5 metres or 8 feet) to a water pipe must have a joint that can withstand at least 50 psi.

Short Form Specifications

General

IPEX Ultra-Rib PVC Pipe is available in sizes 200mm, 250mm, 300mm, 375mm, 450mm, 525mm and 600mm (8" - 24")

Product

The pipe shall be extruded with a smooth interior and with solid reinforcing ribs on the exterior at right angles to the pipe. The space between any two ribs serves as a gasket race for perfect sealing.

Ultra-Rib PVC pipe and fittings shall be certified to CSA B182.4 "Profile (Ribbed) PVC Sewer Pipe and Fittings", and shall meet the requirements of ASTM F794 "Standard Specification for Poly (Vinyl Chloride) (PVC) Ribbed Gravity Sanitary Pipe and Fittings Based on Controlled Inside Diameter.

Material

Ultra-Rib PVC Pipe shall be made of PVC compound having a cell classification of 12454 as defined in ASTM D1784.

Pipe Stiffness

Pipe stiffness must be 320 kPa (46 psi) at 5% vertical deflection when tested according to ASTM D2412.

Molded Fittings

Injection-molded gasketed PVC fittings of ribbed construction shall be certified to CSA B182.1 or CSA B182.2 and used for direct connection to Ultra-Rib pipes in available sizes.

Fabricated Fittings

Fittings fabricated for use with Ultra-Rib pipe shall be certified to CSA B182.4 or ASTM F794 and may include legs of PVC pipe meeting CSA B182.1, B182.2 or ASTM D3034 or F679.

Joints

Gaskets for use with Ultra-Rib pipe are manufactured from EPDM and are designed specifically for use with Ultra-Rib pipe. This unique design is also available in Nitrile.

Sealing gaskets shall meet the requirements of CSA B182.4 and ASTM F477, with the additional requirement that joints shall be able to withstand 345 kPa (50 psi) hydrostatic pressure.

The joint will not leak at 74 kPa (10.8 psi) or 7.5m (25') of head with –74.2 kPa (22") Hg vacuum with spigot under 5% ring deflection and joint at full axial deflection.

Lubricant

Assembly of Ultra-Rib pipe and fittings shall be done in accordance with the manufacturer's directions using only IPEX PVC pipe lubricant. Substitute lubricants shall not be used. IPEX lubricant shall be applied to the inside of the bell to be joined, to a uniform thickness for a distance inside the bell equivalent to three ribs from outside edge.

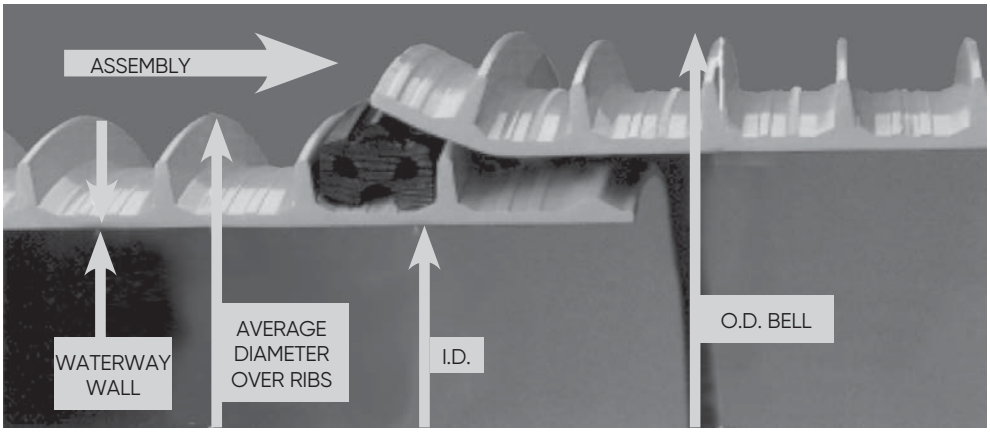
Color Coding

Pipe shall be color coded green.

Dimensions:

Size Range of 200mm – 600mm (8" - 24")

Size		Avg. ID		Avg. Diameter over Ribs		OD at Bell		Waterway Wall	
in	mm	in	mm	in	mm	in	mm	in	mm
8	200	7.89	200	8.80	224	9.78	248	0.087	2.20
10	250	9.86	251	11.00	280	12.22	311	0.091	2.30
12	300	11.74	298	13.10	333	14.59	371	0.102	2.60
15	375	14.37	365	16.04	408	17.82	453	0.110	2.80
18	450	17.65	448	19.57	497	21.77	553	0.130	3.30
21	525	20.75	527	22.80	579	25.14	638	0.160	4.06
24	600	23.50	597	25.61	650	28.24	717	0.180	4.58



ULTRA-X2™ PROFILE PIPE

Ultra-X2 is a dual wall profile pipe. It is manufactured with a corrugated outer wall which is heat fused to the smooth inner wall. Ultra-X2's construction provides ring stiffness and a low "n" value for optimized hydraulic performance.





Applications:

Storm drainage, sanitary drainage, highway and culvert and gravity industrial lines.







Standards

Certified to CSA B182.4

Conforms to ASTM F794

B182.4 F794 CSA B182.4

Joint Tightness and Infiltration

Ultra-X2 has extremely tight joints. Even though it is designed as a non-pressure drainage pipe, its joints can withstand a hydrostatic pressure of 15 psi. This allows it to perform even in the toughest conditions – surcharged sewers or high groundwater conditions.

Dimensions

Nominal Pipe Size		OD		ID		Crest Wall Thickness		Liner Wall Thickness		Insertion Force
mm	in	mm	in	mm	in	mm	in	mm	in	
750	25.53	816.6	32.15	749.2	29.50	3.7	0.15	5.6	0.22	985 lbf
900	35.43	984.6	38.76	901.4	35.49	3.3	0.13	4.6	0.18	1000 lbf

Short Form Specifications

General

IPEX Ultra-X2 PVC Pipe is available in sizes 750mm and 900mm (30" & 36")

Product

Ultra-X2 PVC pipe and fittings shall be certified to CSA B182.4 "Profile PVC Sewer Pipe and Fittings", and shall meet the requirements of ASTM F794 "Standard Specification for Polyvinyl Chloride (PVC) Profile Gravity Sanitary Pipe and Fittings Based on Controlled Inside Diameter.

Material

Ultra-X2 PVC Pipe shall be made of PVC compound having a cell classification of 12454 as defined in ASTM D1784.

Pipe Stiffness

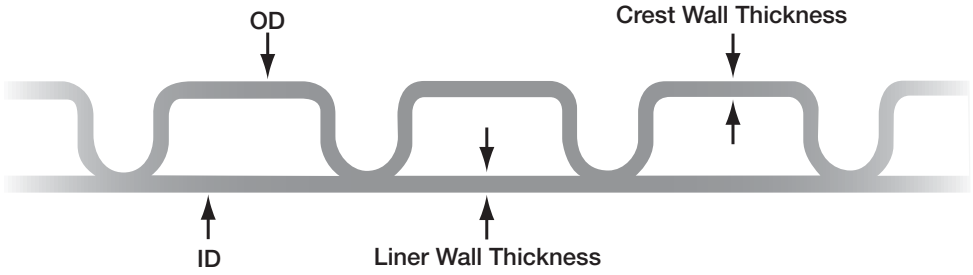
Pipe stiffness must be 320 kPa (46 psi) at 5% vertical deflection when tested according to ASTM D2412.

Lubricant

Assembly of Ultra-X2 pipe shall be done in accordance with the manufacturer's directions using only IPEX PVC pipe lubricant. Substitute lubricants shall not be used. IPEX lubricant shall be applied to the inside of the bell to be joined, to a uniform thickness for a distance inside the bell equivalent to three corrogated profiles from the outside edge.

Color Coding

Pipe shall be color coded green.



PVC MANHOLES AND ACCESS CHAMBERS

IPEX manholes and access chambers are non-corroding, non-infiltrating manholes and chambers designed to maximize system access while minimizing maintenance requirements. The factory made benching is made of chemical resistant FRP or Polypropylene material, while the barrel and chimney are manufactured from IPEX Centurion™ pipe. The 1050mm and 1200mm (42" and 48") manholes can be equipped with special stainless steel steps, while the 600mm (24") access chamber is designed to allow inspection equipment or flushing equipment easy access to the sewer system. In all cases, the pre-cast concrete base acts as an anchor to prevent flotation and to stabilize the structure. Since the concrete is never in contact with the effluent or the sewer atmosphere, corrosion is eliminated.





Applications:

Industrial sewer systems, high water table areas, aggressive effluents, vacuum sewer systems.







Access Chambers vs. Manholes

With today's emphasis on occupational health and safety, most municipalities are focused on minimizing the degree of confined space work occurring in their underground systems. This is where access chambers come in.

An access chamber differs from a manhole in that it is too small to allow man entry into a sewer. It is typically from 450mm (18") to 600mm (24") in diameter and is large enough to allow the insertion of cameras or flushing equipment into the system. The major advantage is that they allow improved access to the system while minimizing the maintenance concerns associated with concrete manholes. In addition, they are cost efficient to install.

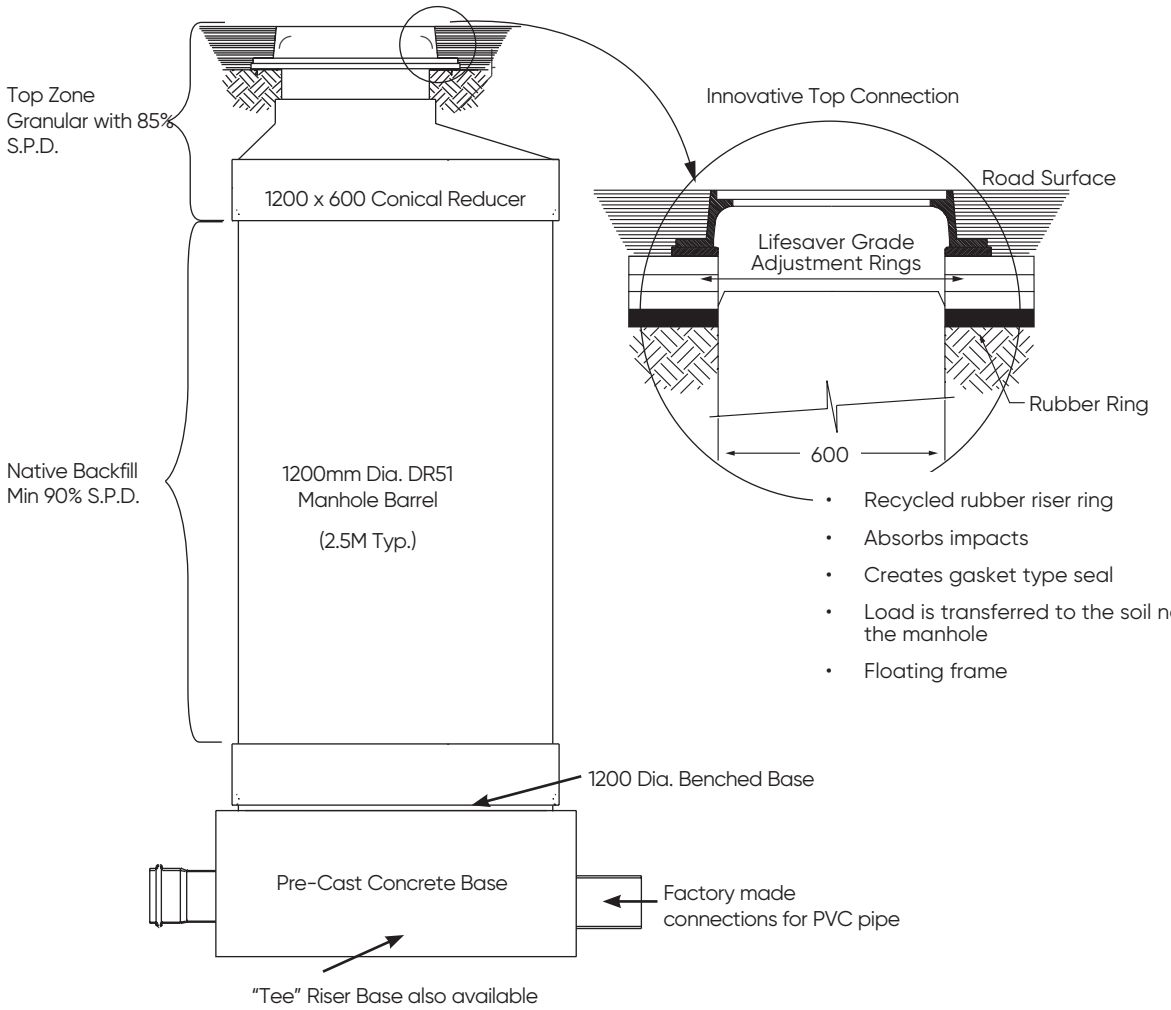
The best choice for a given system depends on a number of factors, including:

- Degree of man access required
- Size of piping system
- Number of direction changes

Ultimately, a combination of manholes and access chambers can be used for a system, with access chambers used for straight connections and full size manholes for any changes of direction

PVC Manhole Installation

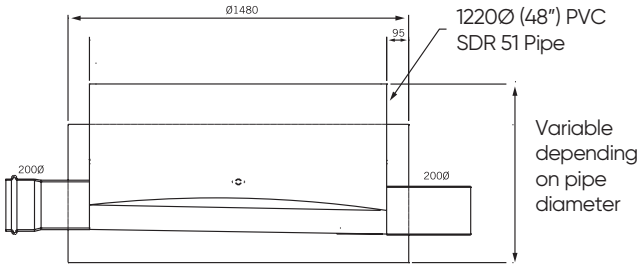
Precast Base Type



Available Manhole Bases (2 types)

Precast Base Adapter

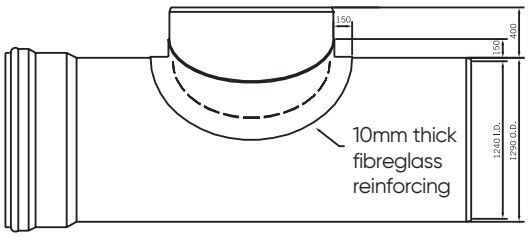
- Available with fiberglass or polypropylene lined base

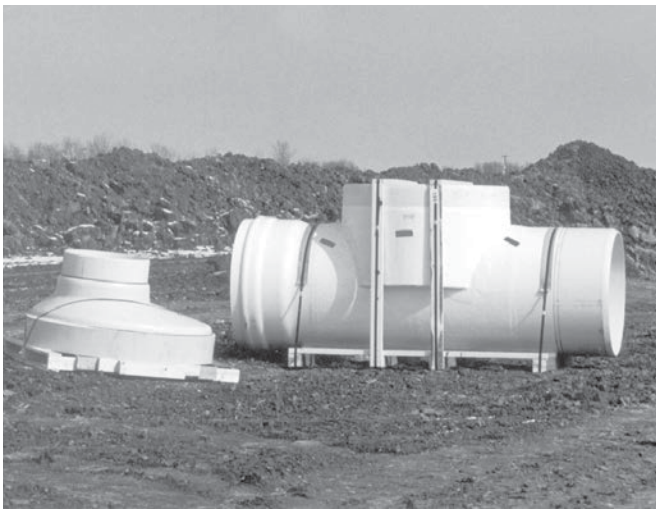




PVC Tee Riser

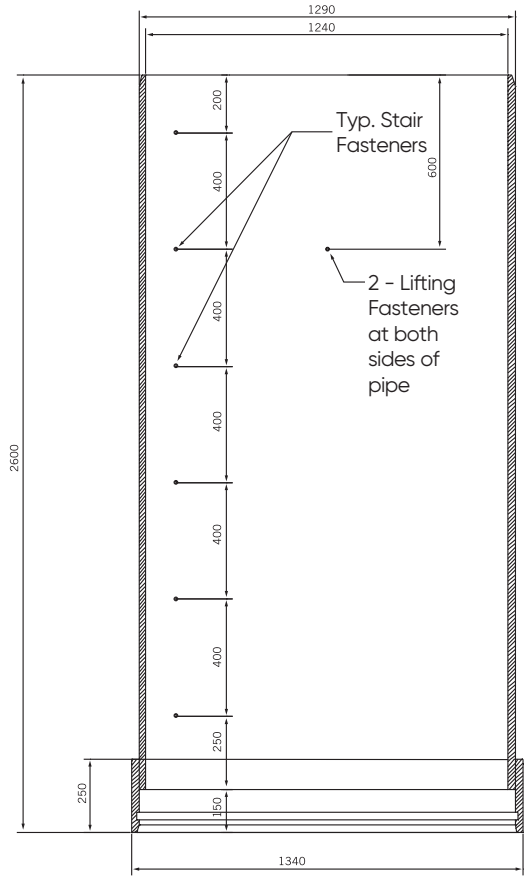
- For mainlines 600mm diameter and larger
- Fabricated PVC fitting
- Bell x Spigot



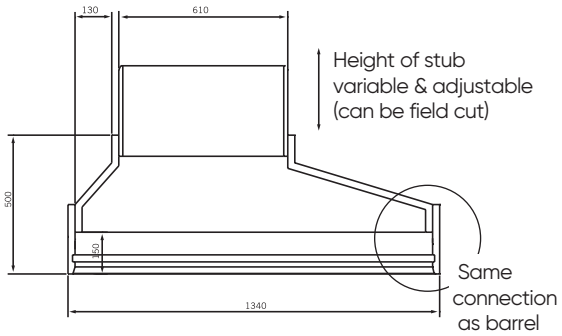


Manhole Details

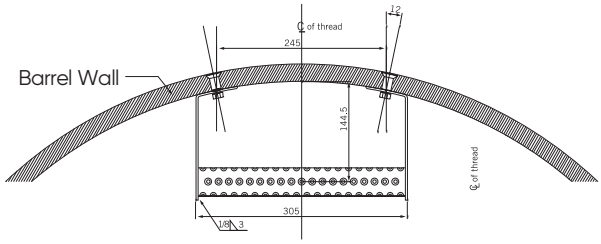
Barrel



Manhole Cone Detail

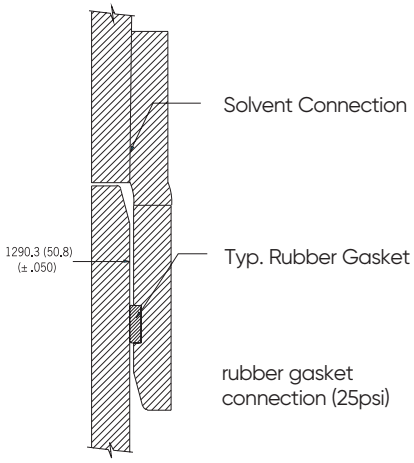


Stair Detail

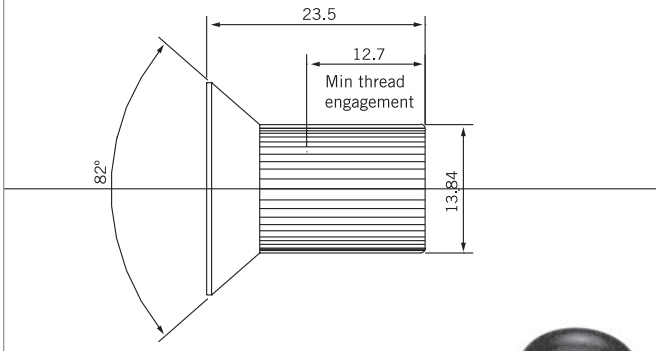


Stainless Steel

Joint Detail



Lifting Anchor



- 3/8" threaded fastener (pressed into wall)
- pullout strength > 8000lbs
- lifting devices supplied on rental basis



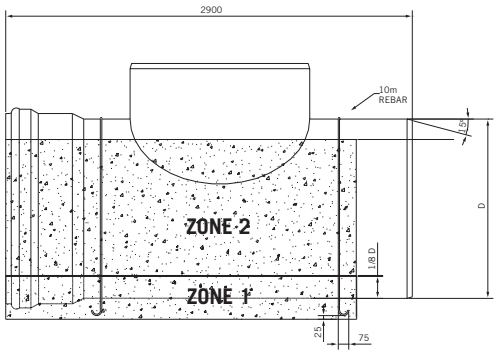
Receiving and Unloading

While it is the customers' decision and responsibility on how PVC manholes are unloaded in the field, we offer these recommendations:

1. Use only IPEX approved lifting devices for unloading. These devices are available for a nominal deposit. Strapping on all shipped goods should not be cut or removed until after unloading to a stable, flat surface.

Standard Concrete Base Installation (Mainline less than 600mm diameter)

1. Over-excavate trench bottom by 100mm.
2. Install 100mm granular material and compact to 95% S.P.D.
3. Install the base, ensuring granular surface is level.
4. In unstable ground conditions consult a qualified Geotechnical Engineer.
5. Install and compact granular material to the top of the pipe.



Vertical Tee-Riser Installation (Mainline 600mm diameter or larger)

The tee-riser must be supported with concrete bedding in order to be properly installed. What follows is a brief description of IPEX's recommendations to ensure a successful installation.

1. Over-excavate trench bottom by 100mm and place blocks to support tee-riser, and maintain clearance for the subsequent concrete pour.
2. Assemble the bell end of the tee-riser to the previously laid PVC sewer pipe. Use the procedures outlined in IPEX's installation guides for sewer or pressure pipe.
3. In order to ensure that the concrete bedding is properly placed, make a form using wood or metal. The form should be shaped so that the horizontal pipe spigot is outside the zone of concrete bedding, otherwise, the concrete will interfere with subsequent pipe assembly.
4. Check again that the tee-riser is evenly supported by the blocks.
5. Install 10m rebars as shown in the drawing.
6. Complete the first pour of 20 Mpa concrete (Zone 1).
7. Ensure that the wood bracing as supplied inside the tee-riser is in place to resist external lateral pressures from the second concrete pour.
8. Allow the concrete installed step 6 to cure. Then pour 20 Mpa concrete in Zone 2 as shown in the drawing.



Barrel Installation

1. Use IPEX approved lifting devices in both lifting fasteners factory installed in barrel exterior (device may be hand-tight only).
2. Lubricate vertical pipe spigot of tee-riser with IPEX 'Ring-Tite™' lubricant.
3. Place barrel bell-end over vertical spigot and apply pressure to top of barrel section for assembly.
4. Should mechanical equipment be required, force should be applied gently using a timber to protect the PVC barrel.
5. Place and compact bedding material as indicated on plans ensuring the compaction equipment does not come in direct contact with barrel.

Conical Top Installation

1. Use IPEX approved lifting devices in both lifting fasteners (device may be hand-tight only).
2. Place conical section bell-end over vertical barrel spigot for assembly in same manner as indicated above for barrel.
3. Ensure compacting equipment is kept a minimum distance of 150mm from conical PVC section surface.

Frame and Cover Installation

1. Measure the distance required to achieve clearance noted on the drawings and mark the stub of the conical top to indicate the finished level.
2. Compact and smooth the granular material as specified to this level.
3. Place the IPEX Rubber Ring over the exposed stub of the conical section.
4. Install the frame and cover (IPEX approved) over the stub on top of the rubber ring.
5. Inside the frame, ensure there is at least 50mm of vertical clearance between the cover and the top of the PVC manhole stub.







VORTEX FLOW™ INSERT (VFI) FOR ODOR AND CORROSION CONTROL

Vortex Flow inserts are specially designed energy dissipating drop structures that virtually eliminate hydrogen sulphide emissions and the associated odor and corrosion problems. This is done by using the flow energy of the sewage to suppress turbulence and aerate the sewage flow. This innovative approach to controlling sewer odor and corrosion was recognized by the American Public Works Association in 1999 with a Technical Innovation Award.

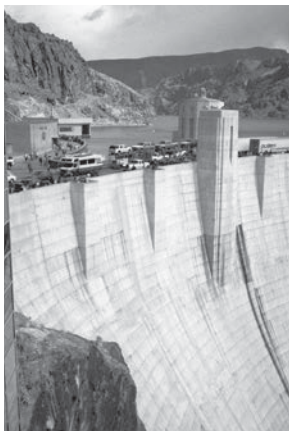


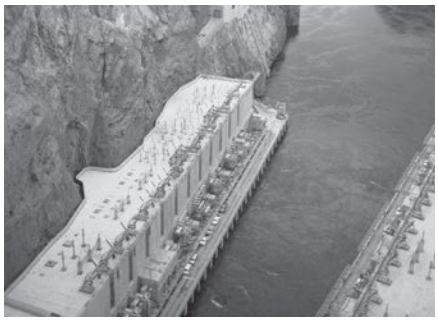
Winner of the 1999 American Public Works Association Innovation Award

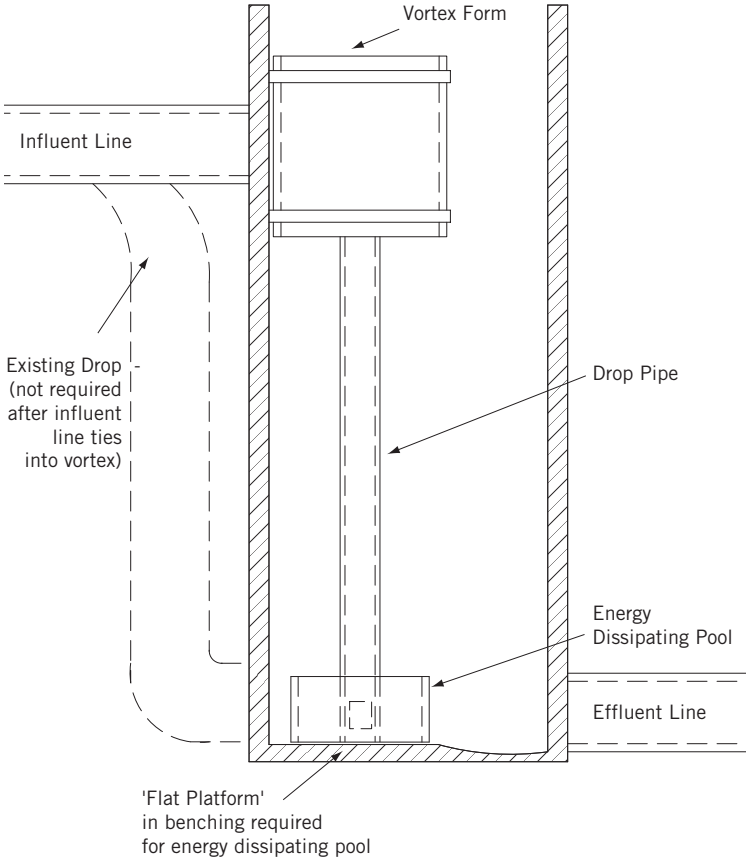


Applications:

Drop structures in sanitary sewage manholes, pumping stations, energy dissipation of high velocity flows in sewer systems and dam outfalls.







Odor and Corrosion in Sanitary Collection Systems

The sulphate ion (SO_4) occurs in varying amounts in water and wastewater. Anaerobic bacteria in wastewater metabolize the SO_4 ion, stripping out the oxygen for respiration and excreting hydrogen sulphide (H_2S). Hydrogen sulphide is not particularly soluble in water, and it comes out of solution very quickly where the flow is turbulent or through air stripping in a sanitary sewer flow.

Forcemain discharges are notorious for H_2S emissions because the sewage is coming from an anaerobic environment (a pipe flowing full), and it is being dumped into a gravity sewer. The flow is usually very turbulent, and air-stripping also occurs. As a result, large quantities of H_2S gas are liberated from the sewage flow.

Once the gas comes out of solution into the atmosphere of a manhole or pipe, the gas can attack and corrode metal directly. The gas is also metabolized by bacteria that live on the inside surfaces of manholes and pipes. The bacteria excrete H_2SO_4, which is commonly known as sulphuric acid. This acid attacks the Portland cement matrix of the concrete, quickly causing deterioration.

The most common method for solving this problem in the past was to inject various chemicals into the sanitary flow in order to oxidize the H_2S in solution. For airborne H_2S, biofilters are typically used to scrub the H_2S from the air. This approach has a number of drawbacks, in that the chemicals used are often expensive, hazardous to handle, or both. Biofilters are quite effective, but require periodic maintenance to ensure proper operation.

The Vortex Flow drop structure can in many cases eliminate the need for both chemical injection and biofilters, and can do so with virtually no maintenance required.

The Design

The Vortex Flow Insert (VFI) was invented by Dr. Eugene Natarius, a noted fluid mechanics expert who devised the VFI to combat a troublesome odor problem from a drop manhole in Minneapolis. While chemical injection was effective in mitigating the problem, the cost of the chemicals was approximately $5,500 per month. The VFI solved the odor problem, and actually outperformed the chemical injection system with respect to H_2S reduction in solution. Dr. Natarius subsequently patented his invention and IPEX is the worldwide licensee of the VFI.

The VFI works by suppressing flow turbulence, effectively dissipating flow energy and by aerating the flow.

The sewage flow is directed into the top form which has a sloped floor designed to increase the flow velocity to super critical velocity (Froude number >1). The form is designed with a spiral form of decreasing radius which directs the flow into the smaller diameter drop pipe. The velocity and the centrifugal forces built up in the top form ensure that a stable vortex is formed in the drop pipe, and that an “air core” will form in the pipe down to the bottom of the structure’s energy dissipating pool.

The air core that forms in the drop pipe has a slight negative pressure as a result of the fluid flow, and as a result it draws any airborne H_2S gas to the bottom of the structure. At the same time, frictional forces on the flow “hugging” the pipe inside wall dissipate the flow energy while minimizing turbulence.

In the energy dissipating pool at the bottom of the structure, the air that was drawn down through the air core is mixed with the effluent. Because the flow exit is submerged, the air cannot simply vent out the bottom of the structure – it must travel through the effluent. As a result, effective aeration occurs, significantly increasing the dissolved oxygen (DO) content of the effluent exiting the structure. The DO oxidizes the dissolved H_2S, to again form the separate H^+ and SO_4 ions, which are much more stable dissolved in water.

Real World Results

The VFI is not simply a theoretical concept — it is a proven method for dealing with odor and corrosion that has been successfully employed around the world. Some of the successful installations include:

Minneapolis MN

A forcemain discharge in a residential area had been a problem for many years, drawing odor complaints from surrounding residents as well as damaging the adjacent gravity sewer pipe as a result of hydrogen sulfide attack. The problem was solved by installing a chemical injection system with a 5000 gallon underground storage tank. Unfortunately, while the sulfide problem was gone, chemical feed costs averaged $5,500 per month. The VFI was installed in an effort to cut down on chemical use, however it was found that the VFI eliminated the need for the chemical feed system, and in many cases outperformed the chemical feed system with respect to sulfide reduction and oxygenation. The results of this project were presented at WEFTEC 2000, and the presentation paper is available from your IPEX representative.

Sarnia, Ontario, Canada

A large manhole that included a 20" forcemain discharge was found to have severe deterioration as a result of hydrogen sulfide attack. The manhole was replaced and the forcemain discharge was equipped with a VFI. The results were immediately apparent as the familiar "rotten egg" smell had disappeared with the installation of the VFI. Furthermore, the benefits of the oxygenation provided by the VFI were immediately noticed at a downstream pumping station, where a persistent H_2S problem previously caused by the forcemain discharge was eliminated.



Hunter Water Corporation, Australia



The picture shows a VFI installed in a barometric loop, which is essentially an area where a forcemain is brought up out of the ground to improve the hydraulic profile of the system.

Hunter Water Corporation (HWC) performed hydrogen sulfide gas concentration monitoring above two working VFI units and carried out liquid sampling in the pumping station wet wells immediately downstream of the units.

According to the HWC data the average hydrogen sulfide gas concentration for one week of continuous monitoring was 1.29 ppm on discharge of the pumping system 1, and 2.27 ppm on discharge of the pumping system 2. For a long force main discharge with a flow drop an average H_2S gas concentration is typically at least ten times higher. The dissolved hydrogen sulfide concentrations from samples were 0.34-0.70 mg/l and 4.2-4.5 mg/l downstream of the system 1 and system 2 discharges accordingly. The HWC compared the levels of dissolved H_2S and found them significantly lower than those recorded at non-vortex barometric loops.



Compared to similar HWC force main systems with barometric loops, odorous gas emission was significantly lower in the VIA installations. HWC concluded that the VIA is effective in reducing H_2S gas emission. VIA implementation allowed reduction of chemical feed dosing rates.

The Vortex Flow Insert Can Reduce Excavation Costs

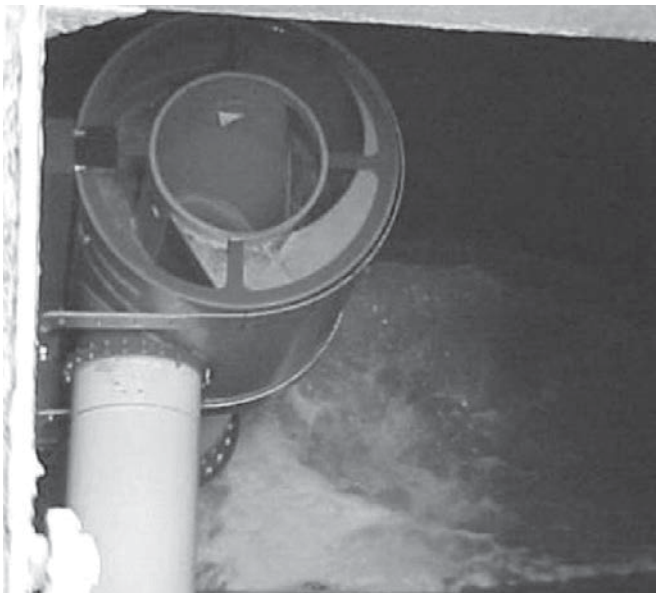
Conventional drop structures can be maintenance problems, and can cause odor and corrosion in a sewer system. As a result, some municipalities have prohibited the use of drop structures for connecting sewers at different elevations. This has resulted in small collector sewers being installed at extremely deep depths of burial so that they can connect to a trunk sewer without the use of a drop. These deep burial installations cost developers (and eventually homeowners) millions of dollars in extra excavation costs.

The VFI actually improves wastewater quality by increasing dissolved oxygen and oxidizing hydrogen sulfide. By installing VFI units on all collector sewer drops as well as on trunk sewers, excavation can be minimized, and odor and corrosion reduced or eliminated.

The Vortex Flow Insert for Pumping Stations

Another problem area for odor and corrosion is pumping station wet wells, where excessive turbulence can increase H_2S emissions significantly. The VFI has been successfully used in pumping stations to reduce odors and properly aerate the flow.

While the drop depths in wet wells are typically less than in manhole drop structures, the VFI effectively suppresses turbulence and oxygenates the wastewater, thereby eliminating odor and corrosion.



Installation

Vortex Flow units can be installed in virtually any drop chamber. Conditions vary among installations, but the unit is typically lifted into place using a backhoe, and then secured to the manhole structure using stainless steel straps. In some cases installation can be accomplished without interrupting or bypassing the sewer flow.

How to Specify a Vortex Flow Insert

In order to complete a preliminary design and estimate a price for a VFI unit, we need to know:

- The minimum flow and the peak flow, including any future growth, of the line under consideration.
- The elevation difference between the incoming line and the outlet
- The dimensions and configuration of the sewer lines, and of the manhole if the structure will be put in an existing manhole.

With this information, a preliminary estimate can be prepared. Exact flow volumes and system layout information is not required at this stage, just the general guidelines.

Specifications

All sanitary sewer drops of 3 feet or more in manholes or pumping stations shall be equipped with Vortex Flow Drop structures as manufactured by IPEX Inc..

Vortex units must be fabricated using AWWA C900 pipe, as well as PVC sheet conforming to ASTM D1248

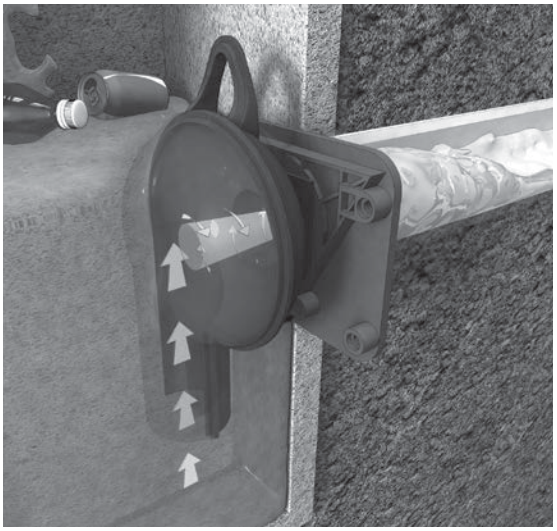
Vortex drop structures must be supplied with shop drawings approved by the Project Engineer, as well as installation instructions. The hydraulic capacity of the unit (both minimum and maximum flows) must be clearly indicated in the submission.

Dimensions

The dimensions of the VFI are dictated by the design flow capacity required. Small units can be designed for collector sewers and may have a top section as small as 14 or 16 inches in diameter. Larger units with capacities up to 100 MGD may be up to 10 feet in diameter. Each unit is custom designed and fabricated for each application.

TEMPEST™ INLET CONTROL DEVICES FOR STORMWATER SYSTEMS

Tempest is a family of cost-effective inlet control devices that work together across a series of catch basins to limit the amount of storm water runoff that can enter a combined sewer system during a storm event. Basement backups and sewer overflows are avoided because storm water surcharges are controlled at the sewer inlet and are allowed to remain in catch basins or temporarily above ground.



In addition to flow control, Tempest systems can also alleviate sewer system odour emissions as well as prevent floating debris from entering the sewer system.

Available in a wide range of patent pending models and pre-set flow rates, Tempest systems can accommodate most storm water flow control requirements from 2 lps to 17 lps and beyond. Application specific solutions can also be engineered to meet your unique needs in both wet and dry catch basin environments.





Constructed from durable PVC, Tempest units are corrosion free and built to last. The Tempest's light weight design accommodates both square and round catch basins and features a universal back plate and interchangeable components with no moving parts that makes the units quick and easy to install over a catch basin outlet pipe.

These devices also include a quick release mechanism to allow easy access for service without the need to drain the installation.

Applications:

Storm water flow control for parking lots, roads and other areas where main line storm sewer capacity must be managed.







LMF ICD



Square Catch Basin Adapter

Low to medium flow
Restricts flow to 2 Lps - 17 Lps
14 preset flow rates
Floatable and odour control
Supplied with neoprene gasket



Round Catch Basin Adapter

HF ICD and Odour Traps ICD



HF Square Catch Basin Adapter

HF Round Catch Basin Adapter

Hi flow
Restricts flow to 15 Lps & >
5 preset flow rates
Floatable and odour control
Supplied with neoprene gasket



Odour Trap Square Catch Basin Adapter

Odour Trap Round Catch Basin Adapter

Option for odour trap only, no flow restriction

MHF Plate or Plug ICD



Square Catch Basin Adapter

Medium to high flow
Restricts flow to 9 Lps and >
5 preset flow rates
Supplied with neoprene gasket



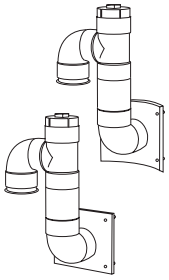
Round Catch Basin Adapter



8″
10″
12″

Medium to high flow
Restricts flow to 9 Lps and >
5 preset flow rates

HF Sump ICD



Square Catch Basin Adapter

High flow
Creates a sump
Restricts flow to 15 Lps and >
5 preset flow rates
Floatable and odour control

Round Catch Basin Adapter

Please contact your local IPEX representative for sizing of a TEMPEST ICD and a quotation

NOTES: In order to assist in choosing the proper TEMPEST ICD and for proper sizing and a quotation, the following information will be required when contacting IPEX for a TEMPEST ICD:

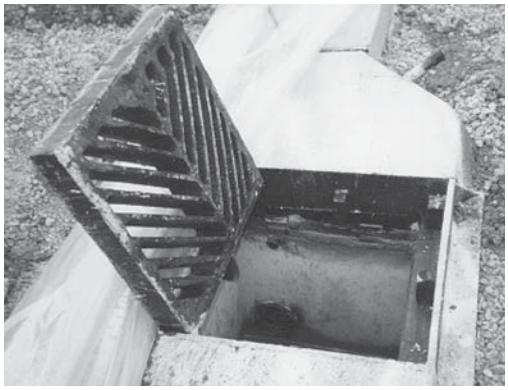
1. Feature(s) requirement: flow, floatable control, odour control
2. Flow requirement
3. Water height (Head / m)
4. Depth of sump / height of outlet pipe
5. Host pipe material
6. Inside diameter of host pipe
7. Catch basin configuration
8. Catch basin structure dimensions



LIFESAVER™ MANHOLE AND CATCH BASIN ADJUSTMENT UNITS

Lifesavers are high impact HDPE adjustment units designed to bring manhole and catchbasin castings up to the exact height of the asphalt or concrete surface of a roadway. These units cushion the impact loads between the cast iron casting and the concrete manhole or catchbasin structure, while eliminating infiltration and undermining. This extends the life of the surrounding roadway.





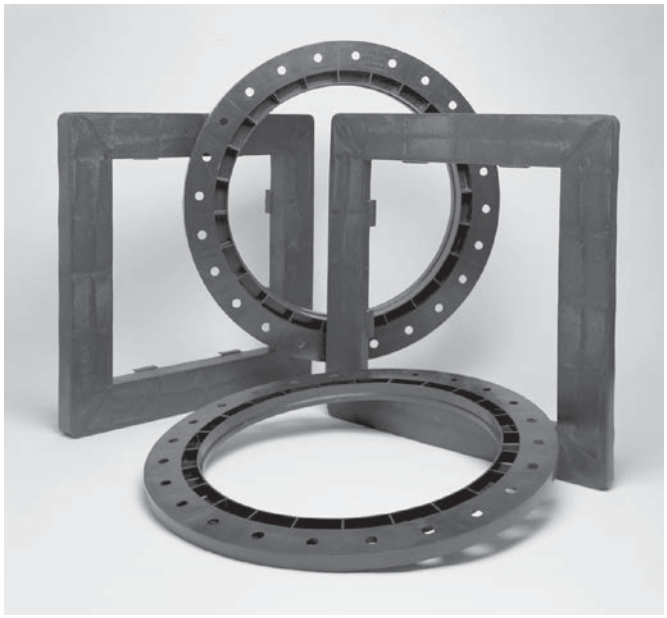
Applications:

Grade adjustments for manholes, catchbasins as well as electrical, telephone and other utility vaults. Recommended for high traffic areas.









Why use Lifesavers?

Concrete adjusting units are difficult to install, impossible to seal and are relatively fragile. They typically do not stand up to repeated impact loads and tend to crack, allowing infiltration of both water and fines, which causes undermining of the surrounding pavement structure. In addition, accurate slope adjustments are difficult because they must be done by sliding shims under the rings, then waiting for the mortar to cure.



Lifesavers eliminate all these problems because:

- Their lightweight, high impact HDPE construction makes them easy to handle. While concrete units can weigh up to 100 lbs or more, a single Lifesaver ring weighs less than 5 lbs.
- The manhole units are sealed using caulk, as opposed to field mixed (and often poor quality) mortar. This eliminates infiltration of both water and fines. In addition, bedding material can be compacted around the adjusting units immediately, while with concrete units the mortar must cure first.
- The catchbasin units, when properly wrapped with filter cloth will allow infiltration into the catchbasin, but will screen out all fines.
- Lifesavers are completely unaffected by chlorides from road salt and hydrogen sulphide from sanitary sewers. Both of these substances attack concrete units

Finally, Lifesavers have been used for many years in some of the most demanding applications in North America, and have been proven to significantly increase the life of the surrounding pavement structures.

Standards

Lifesavers are molded from high density polyethylene conforming to ASTM D1248.

Dimensions

Flat Manhole Adjusting Ring

Manhole Opening		DIM A		DIM B		DIM C	
in	mm	in	mm	in	mm	in	mm
24	610	23.75	603.3	33.50	850.9	5.00	127
27	686	26.75	679.5	36.50	927.1	5.00	127
30	762	29.75	755.7	39.50	1003.3	5.00	127
32	813	31.75	806.5	41.50	1054.1	5.00	127
34	864	33.75	857.3	41.50	1054.1	5.00	127

Sloped Manhole Adjusting Ring

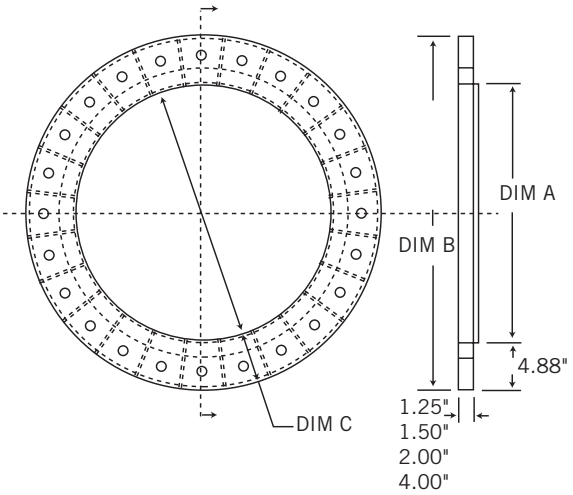
Manhole Opening		DIM D		DIM E	
in	mm	in	mm	in	mm
24	610	1.5	38	0.75	19
27	686	1.5	38	0.75	19
30	762	2.25	57	1.5	38
32	813	2.25	57	1.25	32
34	864	2.25	57	1.25	32

LIFESAVER MANHOLE ADJUSTMENT RINGS

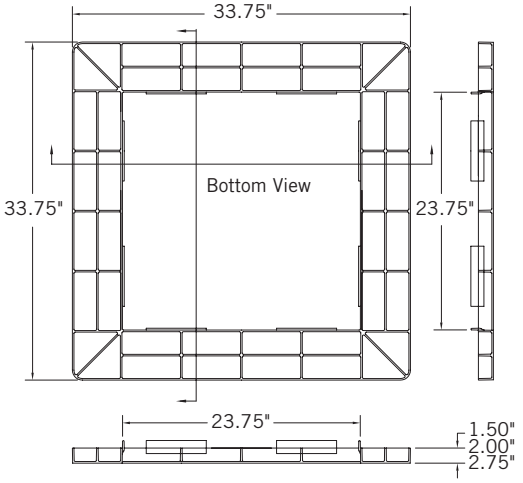


LIFESAVER CATCH BASIN ADJUSTMENT FRAMES

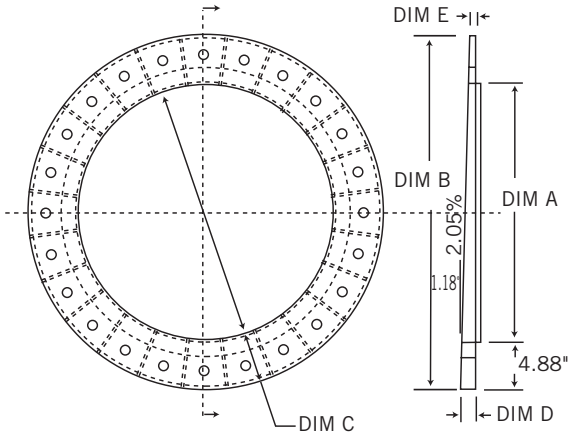




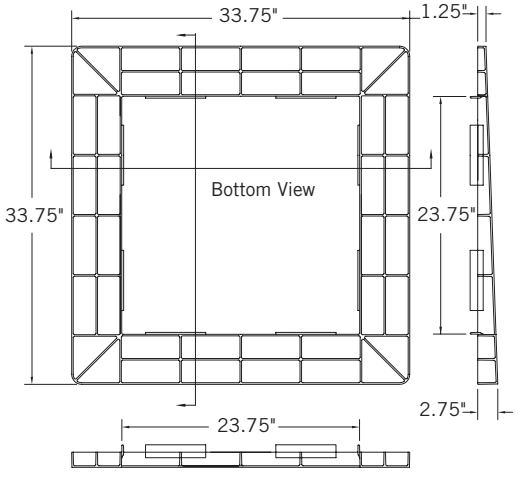
Flat Manhole Adjusting Ring



Flat Rectangular Catch Basin Adjusting Frame



Sloped Manhole Adjusting Ring

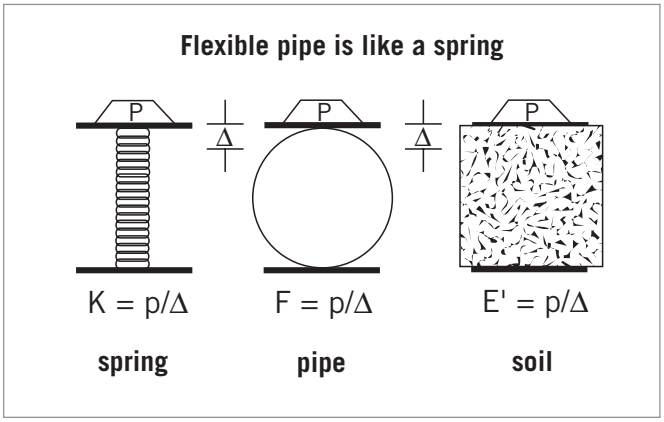


Sloped Rectangular Catch Basin Adjusting Frame

Structural Design

PVC pipes are classified as flexible conduits, which means they are designed to transfer loads to the bedding envelope surrounding the pipe by deflecting. A flexible conduit is generally defined as one that can deflect more than 2% of its diameter without damage.

Perhaps the easiest way to visualize pipe-soil interaction is to consider the spring analogy that was used by Dr. A. Moser in his authoritative textbook "Buried Pipe Design".[2]



The ability to deflect away from vertical load is what gives PVC pipe its load carrying capability. The arching action of the soil over the pipe tends to reduce the load on the conduit, while the load that is applied is transferred to the surrounding bedding.

High Load Carrying Capabilities Even with Marginal Bedding

The pipe-soil system formed by PVC pipe is surprisingly strong. While PVC pipes are routinely installed with depths of bury exceeding 50 feet (particularly in landfill applications), experimental work has shown that Ultra-Rib pipe is capable of easily withstanding depths of bury up to 100 feet. Concrete pipe installed with identical bedding parameters collapsed. For a complete research report on this research completed at Utah State University, please contact your IPEX representative.

Deflection is Not a Bad Thing

Flexible pipes have a different failure mode than rigid pipes. Rigid pipes crack and eventually collapse under excessive load, whereas flexible pipes simply continue to deflect. PVC sewer pipes can typically deflect up to 30% of their diameter before any leakage occurs at the joints or damage to the pipe. The deflection limit for a PVC pipe is typically set at between 5% and 7.5%, which means that there is a safety factor of between 4 and 6 for leakage.

Rigid pipe manufacturers often point to deflection as a drawback when using PVC pipe, however this simply reflects a lack of understanding of the pipe-soil mechanism. Rigid pipes must also deflect slightly to carry load, but they respond to this slight deflection by cracking. As a result, while the performance limit for flexible pipe is the allowable deflection, the performance limit for concrete pipe is an allowable crack width. While concrete pipe manufacturers claim that their product can "self heal" small cracks, it is advisable to check these installations with a low pressure air test to ensure that the cracked pipe is not leaking.

[2] Moser, A.P., "Buried Pipe Design, 2nd Edition, pp.22

Calculating Loads on PVC Sewer Pipes

Buried structures are subjected to dead loads from the soil above (and sometimes from structures or buildings) the pipe, and to live loads, which are applied by vehicles or other bodies placed above the pipe temporarily.

The maximum possible soil load on a PVC pipe is known as the prism load, which is the pressure exerted by the full "block" of soil above the pipe. In reality, the actual load is somewhat less than this value, however assuming prism load conditions contributes to a conservative design.

Example

The prism load can be easily calculated if the soil density is known. For example, assume a soil density of 120 lb/ft^3 and a depth of bury of 10 feet.

P = soil pressure, (lb/ft^2)

w = soil density, (lb/ft^3)

H = Depth of bury (ft.)

P = wH = (120 lb/ft^3)(10 ft.) = 1200 lb/ft^2 = 8.3 lb/in^2

Calculating live loads is more complicated and involves using the Boussinesq Solution for stresses in a semi-infinite elastic medium due to a point load applied at the surface[3,4]. While relatively simple to solve, most designers opt to use standard loads that have been developed over the years.

The dead load and the live load is simply added together to get the total load on the pipe, which is then used to predict the long-term deflection in the pipe installation.

Live Loads Transferred to Buried Pipe							
Depth of Bury (ft.)	Live Load transferred to Pipe (lb/in^2)			Depth of Bury (ft.)	Live Load transferred to Pipe (lb/in^2)		
	Highway - H_20	Railway E80	Airport		Highway - H_20	Railway E80	Airport
1	12.5	Not Rec.	Not Rec.	14	*	4.17	3.06
2	5.56	26.39	13.14	16	*	3.47	2.29
3	4.17	23.61	12.28	18	*	2.78	1.91
4	2.78	18.4	11.27	20	*	2.08	1.53
5	1.74	16.67	10.09	22	*	1.91	1.14
6	1.39	15.63	8.79	24	*	1.74	1.05
7	1.22	12.15	7.85	26	*	1.39	*
8	0.69	11.11	6.93	28	*	1.04	*
10	*	7.64	6.09	30	*	0.69	*
12	*	5.56	4.76	35	*	*	*

Notes:

1. Table taken from the Uni-Bell Handbook of PVC Pipe - 4th Edition, pp. 210
2. H20 load simulates 20 ton truck traffic + impact (source ASTM A796)
3. E80 load simulates 80,000 lbs/ft railway load + impact (ASTM A796)
4. Aircraft load simulates 180,000 lb. dual tandem gear assembly, 26 inch spacing between tires and 66 inch centre spacing between fore and aft tires under a rigid pavement 12" thick + impact

[3,4] More information on this calculation can be found in virtually any Soil Mechanics textbook. One of the best is "Soil Engineering" by M.F. Spangler. Information can also be found in Moser's "Buried Pipe Design" and the Uni-Bell Handbook of PVC Pipe.

The Modulus of Soil Reaction, E'

The modulus of soil reaction is basically a measure of the soil stiffness of the bedding surrounding the pipe. Since flexible pipe transfers load to the surrounding bedding, the E' (known as E prime) value used for calculations has a significant impact on the predicted deflection. Over the years, there have been many studies, done both in the laboratory and the field that have established reasonable design values for E'. Perhaps the most comprehensive work has been completed by Amster Howard of the U.S Bureau of Reclamation:

TABLE 7.3
AVERAGE VALUES OF MODULUS OF SOIL REACTION, E'
(For Initial Flexible Pipe Deflection)

Soil type-pipe bedding material (Unified Classification System[a]) (1)	E' for Degree of Compaction of Bedding, in pounds per square inch			
	Dumped (2)	Slight, <85% Proctor, <40% relative density (3)	Moderate, 85%-95% Proctor, 40%-70% relative density (4)	High, >95% Proctor, >70% relative density (5)
Fine-grained Soils (LL > 50)[b] Soils with medium to high plasticity CH, MH, CH-MH	No data available; consult a competent soils engineer; Otherwise use E' = 0			
Fine-grained Soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with less than 25% coarse-grained particles	50	200	400	1,000
Fine-grained Soils (LL < 50) Soils with medium to no plasticity, CL, ML, ML-CL, with more than 25% coarse-grained particles	100	400	1,000	2,000
Coarse-grained Soils with Fines GM, GC, SM, SC[c] contains more than 12% Fines				
Coarse-grained Soils with Little or no Fines GW, GP, SW, SP[c] contains less than 12% Fines	200	1,000	2,000	3,000
Crushed Rock	1,000	3,000	3,000	3,000
Accuracy in Terms of Percentage Deflection[d]	±2	±2	±1	±0.5

[a]ASTM Designation D 2487, USBR Designation E-3.
[b]LL = Liquid limit.
[c]Or any borderline soil beginning with one of these symbols (i.e. GM-GC, GC-SC).
[d]For ±1% accuracy and predicted deflection of 3%, actual deflection would be between 2% and 4%.

Note: Values applicable only for fills less than 50 ft (15 m). Table does not include any safety factor. For use in predicting initial deflections only, appropriate Deflection Lag Factor must be applied for long-term deflections. If bedding falls on the borderline between two compaction categories, select lower E' value or average the two values. Percentage Proctor based on laboratory maximum dry density from test standards using about 12,500 ft-lbs/cu ft (598,000 J/m^3) (ASTM D 698, AASHTO T-99, USBR Designation E-11). 1 psi = 6.9 kPa.

SOURCE: "Soil Reaction for Buried Flexible Pipe" by Amster K. Howard, U.S. Bureau of Reclamation, Denver, Colorado. Reprinted with permission from American Society of Civil Engineers.

Predicting Long Term Deflection using the Modified Iowa Formula

The Modified Iowa formula is an empirical equation that has been developed based on work originally done in the early 1900's, and is the most commonly used expression to calculate deflection in any flexible conduit.

$$\frac{\%\Delta Y}{D} = \frac{(D_L KP + KW')(100)}{(0.149\frac{F}{\Delta Y} + 0.061E')}$$

Where:

ΔL = Deflection Lag Factor (1.0 for Prism loads)

K = Bedding Constant (0.1)

W' = Live load, lbs/in^2

F/DY = Pipe Stiffness, lbs/in^2

E' = Modulus of soil reaction, lbs/in^2

Example: A 24" Ultra-Rib pipe is to be installed 35 feet under a railway track and bedded using highly compacted (>90% Proctor density), well graded granular material. The soil density is 120 lb/ft^3.

Calculate the expected ring deflection

1 Calculate the Dead Load:

Prism load = wH = (35ft)(120lb/ft^3)=4200lb/ft^2=29 lb/in^2

2 Calculate the Live Load:

From the Live Load table it can be seen that at 35 feet the effects of an E80 Railway load are negligible.

3 Choose the appropriate E' value

From Amster Howard's work shown in the previous table for compacted crushed rock the E' value is 3000 lb/in2

4 Use the Modified Iowa Formula to Calculate the Deflection

$$\frac{\%\Delta Y}{D} = \frac{(D_L KP + KW')(100)}{(0.149\frac{F}{\Delta Y} + 0.061E')} = \frac{(1 \times 0.1 \times 29) + (0.1)(0)}{(0.149)46 + 0.061(3000)} \times 100 = 1.5\%$$

Table 1 – Percent (%) Deflection for SDR35, Ultra-Rib, Ultra-X2 and Perma-loc V Pipes

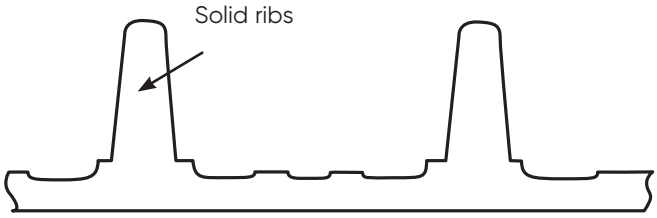
ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	E' psi (kPa)	HEIGHT OF COVER ft. / m	1 / 0.3	2 / 0.6	3 / 1	7 / 2	10 / 3	13 / 4	16 / 5	20 / 6	23 / 7	26 / 8	30 / 9	33 / 10	50 / 15
Manufactured Granular Angular	CLASS I	90%	3,000 (20 700)		0.7	0.5	0.3	0.4	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.4	2.2
Clean Sand & Gravel	CLASS II	90%	2,000 (13 800)		1.1	0.7	0.5	0.5	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.1	3.2
		80%	1,000 (7 000)		2.0	1.4	1.0	1.0	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	6.0
Sand & Gravel with Fines	CLASS III	85%	500 (3 500)		n/r	2.5	1.7	1.8	2.2	2.9	3.7	4.4	5.1	5.9	6.6	7.3	11.0
Silt & Clay	CLASS IV	85%	400 (2 760)		n/r	3.0	2.1	2.2	2.6	3.5	4.4	5.3	6.1	7.0	7.9	8.8	13.1

1. Deflection values shown include effect of H_20 live load and dead load.
2. External loading based upon a prism load of soil weight of 1 900 kg/m^3 (120 lbs. per cubic foot).
3. Bedding classifications correspond to ASTM D2321.
4. The deflection lag factor is 1.0 for a prism load.
5. Recommended maximum deflection of 7.5% provides a generous 4 to 1 factor of safety.
6. n/r = not recommended.

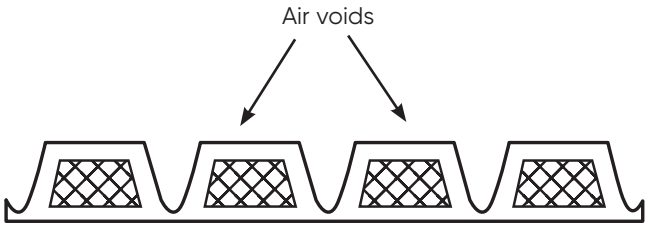
Profile wall vs. Smooth wall Pipe

The performance characteristics of SDR35 pipe, Ultra-Rib / Ultra-X2 pipe are identical. They have similar internal diameters, identical ring stiffness of 320 kPa (46 psi), and the same tight joints (50 psi). So, when should one specify Ultra-Rib / Ultra-X2 and when should it be SDR35?

The secret to a successful specification is to specify as many products as possible that meet a certain performance standard. Since SDR35 and Ultra-Rib / Ultra-X2 are identical from a performance perspective, both products can be specified for sanitary and storm sewer applications.



Ultra-Rib Open Profile



Double Wall Corrugated (DWC) Closed Profile

Longevity and Durability of PVC Pipe Systems

Studies undertaken in Europe and North America confirm that PVC has one of the longest life cycles of any sewer pipe material. These studies include:

Uni-Bell PVC Pipe Association –
Examination of 15 Year Old Sewer Pipe

In this study a sewer pipe that had been in service for 15 years in Dallas, Texas was excavated and tested according to ASTM standards. The pipe met all current standards with the exception of the outside diameter, on which it was outside the allowable tolerance by 0.002 of an inch.

Wavin International – The Result of 30 Years Research into the Life of Pipe Systems

This study consisted of the examination of over 26,000 metres of sewer pipe installed in some of the most difficult conditions in Europe over the last 30 years. Some of the conclusions of the study were:

- PVC piping systems can be expected to last for several hundred years
- Good results are possible even when the pipes are installed under extremely difficult conditions, such as cohesive clay or peat.
- Even after up to 30 years service, there was no difference in the wall thickness between the "washed" portion of the pipes that carried wastewater and the "unwashed" portion near the crown of the pipes. This indicated abrasion wear was simply not an issue with these pipes.

Reinhard Nowack, Thomas Hulsman –
70 Years of Experience with PVC Pipes

The first PVC pipes for commercial use were produced in Germany in the mid-1930's. During this study a number of these pipes were excavated and tested. Although these pipes were pressure pipes, many of them were used in chemical transfer applications, and have not had any decrease in service properties. Some of the conclusions of this study were:

- Even some of the earliest commercially produced pipes, which had a rated lifespan of only 50 years, were still performing well 70 years later.
- Better machinery available today and advanced compounding means that pipes produced today will have a longer lifespan than the pipes examined in this study

The fact that PVC is not affected by the aggressive chemicals commonly found in sewage (sulphides, chlorides) means that it has a virtually unlimited lifespan in these applications. A minimum life cycle of 100 years is a conservative value to use when carrying out life-cycle costing calculations.

Chemical and Abrasion Resistance

Sanitary sewers, particularly in industrial areas, can be an extremely aggressive environment for piping materials. Hydrogen sulphide, chlorides from road salt as well as various substances in wastewater can attack concrete and metal components of sewer systems. Furthermore, abrasion caused by grit in wastewater can accelerate the decay process through abrasion and wearing action. Fortunately, PVC and other thermoplastics are virtually immune to attack from these chemicals and are highly resistant to abrasion.

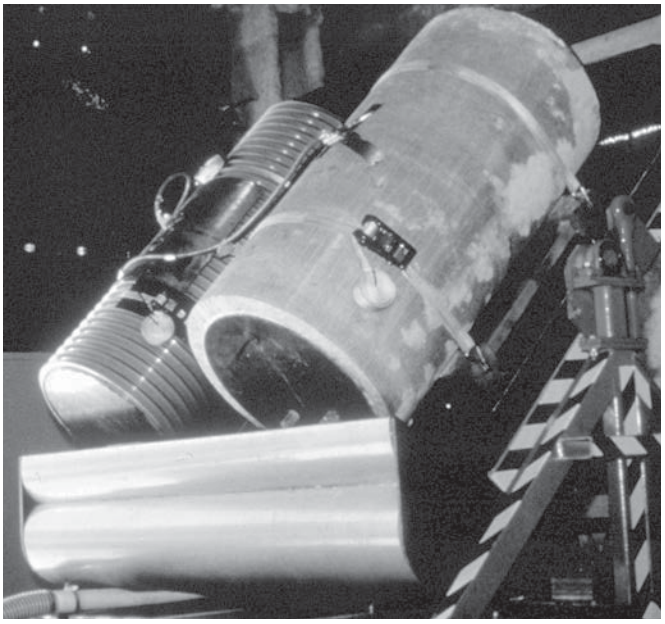
Chemical Attack

Various studies have been undertaken with respect to the chemical resistance of PVC piping systems. Most of these studies have dealt with the issue of permeation by organic chemicals and the most common conclusion is that PVC pipe forms an effective barrier against organic contamination, with an effective permeation time in the order of many centuries even at extremely high levels of organic contamination.

With gravity sewer pipe the concern is typically whether gasoline, oil or other chemical spills could compromise the structural integrity of a PVC culvert or sewer pipe. Testing with various substances has shown conclusively that it is virtually impossible for PVC pipe to be affected by a spill. For example, PVC pipe has been exposed to pure gasoline for years with no effect[5]. While chemicals such as acetone can eventually damage PVC pipe, the effluent running through the pipe would have to be almost pure acetone and would have to run for hours for damage to occur.

Abrasion

Storm sewers and high velocity sanitary sewers can have a significant portion of grit in their flows that can potentially abrade a concrete sewer pipe. Testing carried out at California State University confirms that PVC pipe is considerably more durable than concrete pipe with respect to abrasion.



The results from California State clearly indicate that abrasion should be considered when designing sanitary or storm sewer systems. While it is true that very few concrete sewers have ever failed as a result of abrasion alone, abrasion tends to accelerate the corrosion process of both concrete and reinforcing steel

When considering Ultra-Rib, Ultra-X2 and SDR35 PVC pipes, abrasion can be virtually eliminated as an issue.

Infiltration and Exfiltration

The tight tolerances of Ring-tite, Enviro-Tite, Ultra-X2 and Ultra-Rib allow for extremely tight gasketed joints. The end result is a pipe joint that allows zero infiltration and exfiltration. In order to meet ASTM and CSA standards, all joints must withstand hydrostatic pressure levels of 100kPa (15 psi) as well as a vacuum pressure of -75 kPa (-11 psi).

In fact, the joints of Ring-Tite, Enviro-Tite and Ultra-Rib can withstand pressures in excess of 345 kPa (50 psi). In many jurisdictions a 50 psi capable joint is required when installing a sewer within 8 feet of a water main.

While properly installed IPEX sewer pipes will have zero infiltration, the ASTM standard actually allows a maximum of 2.3 litres per mm diameter per kilometer per day (25 U.S. gal/in. dia/mile/day). This allowance recognizes that PVC sewer systems are often constructed with concrete manholes which generally allow a certain amount of infiltration.

[5] Hoogensen Metallurgical Engineering Ltd., "Examination of Submitted PVC Pipe Section", Report to IPEX, December 1998

Root Intrusion

Root choked clay and concrete sewers cause millions of dollars worth of damage each year due to sewer backups. IPEX sewer pipe joints are immune to root penetration for two reasons:

- They are tight enough to resist even the thinnest root filaments penetrating
- They do not provide a water source for the roots, so they do not attract root growth.

Each of these points has been proven both through field and laboratory testing.

Gravity Flow Systems: Manning's Equation

The most common procedure for calculating open channel or partially full pipe flow conditions is to use the Manning formula below:

$$V = \frac{1.49}{n} r^{2/3} s^{1/2}$$

Where: V = the average velocity at a cross section ft/sec

R = the hydraulic radius, ft

S = slope, ft/ft

n = the coefficient of roughness

The "n" factor varies both with the degree of roughness of the inside of the pipe, and the flow velocity. Higher flow velocities tend to reduce the "n" factor in sewers as solids deposition and slime build-up on the bottom of the pipe is reduced.

Designing with the PVC sewer pipe, an "n" factor of 0.009 is recommended.[6] This is supported by a large number of scientific studies, many of which were carried out on "in service" pipes that had been operating for many years. The "n" values in these studies were found to range between 0.007 and 0.011. no published study has ever found an "n" value as high as 0.013 for a PVC system in any sewer operation even at minimum velocities of 2 ft/s (0.6 m/s). Please contact us if you wish to review the results of these studies.

Average Values of the Manning Roughness Factor

Material	Manning n
PVC	.009
Concrete	.013
Cast iron	.015

The relatively low "n" values associated with PVC pipe are a result of various factors:

- Smooth, nonporous inside surface of the pipe
- Longer laying lengths (i.e. fewer joints)
- Lower profile gap at the joints
- Chemical and abrasion resistance of the material

By designing PVC sewer systems with the scientifically appropriate Manning value of 0.009, sewers can be installed at tighter grades, thus reducing excavation costs and disturbance. In some cases, it may even be possible to downsize the pipe while maintaining a particular flow capacity.

[6] Uni-Bell PVC Pipe Association; "Handbook of PVC Pipe" 4th Edition, August 2001, pp.359

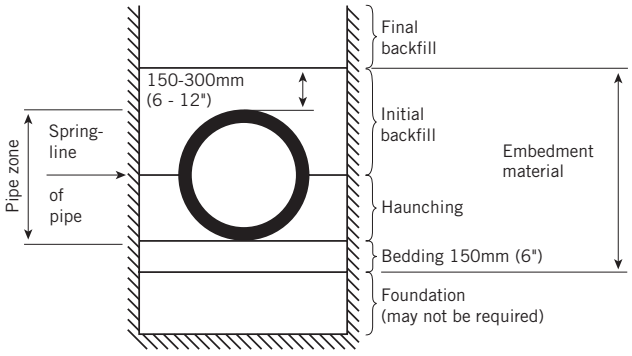
Installation of PVC Sewer Systems

An understanding of flexible conduit terminology is essential for the installer. The soil class and density realized in the bedding, haunching and initial backfill zones are important factors in achieving a satisfactory installation of PVC pipe.

Much of the installation information can also be found in Canadian Standards Association (CSA) Standard B182.11, entitled, "Recommended Practice for the Installation of Thermoplastic Drain, Storm and Sewer Pipe and Fittings" or ASTM Standard D2321, entitled, "Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity Flow Applications."

Trench Zones

The following figure has been prepared to illustrate the various zones used with flexible pipe terminology.



Foundation – A foundation is required when the trench bottom is unstable. Any foundation that will support a rigid pipe without causing loss of grade or structural breakage will be more than adequate for PVC pipes.

Bedding – The bedding directly underneath the pipe is required only to bring the trench bottom up to grade. It should not be so thick or soft that the pipe will settle and lose grade. The sole purpose of the bedding is to provide a firm, stable and uniform support of the pipe. A bedding thickness of 100 mm (4") is most times sufficient. The engineer may wish to increase the bedding to 150 mm (6") for ledge rock foundations.

Haunching – This area is the most important in terms of limiting the vertical deflection of the flexible pipe. Pipe support is obtained in the haunch zone by compacting soil in both directions away from the pipe to the undisturbed trench walls.

Initial Backfill - This zone begins above the springline to a level 150 mm (6") to 300 mm (12") above the top of the pipe. Compaction here will give little additional side support to PVC pipe, but may be required to maintain stability of any above ground surfaces (i.e. roads or sidewalks).

Note: The particle size recommended for the three zones described above should not exceed 38 mm (1.5") for Ring-Tite, Enviro-Tite, Ultra-Rb and Ultra-X2.

Final Backfill - The remainder of the trench fill above the initial backfill provides no support for a PVC pipe and should be free of stones 150 mm (6") and larger. Compaction may be required for reasons other than support of the PVC pipe since this zone is very significant in supporting the above ground surfaces (i.e. roads or highways).

Embedment Materials

Some general rules about all soils to be used in a buried pipe-line trench include that they must be free of sharp objects, sticks, large clumps, frozen material, organic materials and boulders.

Most of the soils commonly found can be classified into one of the following categories, which are referenced from ASTM D2487.

Class 1

Angular, 6 mm to 38 mm (1/4 - 11/2") graded stone, including a number of fill materials such as coral, slag, cinders, crushed stone or crushed shells.

Class 2

Coarse sands and gravels with a maximum particle size of 38 mm (11/2"), including various graded sands and gravels containing small percentages of fines, generally granular and non-cohesive.

Class 3

Fine sand and clayey gravels, including fine sands, sand-clay mixtures and gravel-clay mixtures.

Class 4

Silt, silty clays, and clays including inorganic clays and silts of medium to high plasticity and liquid limits.

Class 5

Includes organic soils such as frozen earth, debris and other foreign materials. These materials are not recommended for use in the bedding, haunch or initial backfill zones.

Note: The performance of a flexible conduit does not depend only on the class of embedment materials used, but more importantly, on the density achieved in compaction of the haunching material.

Selection of Embedment Materials

Soil to be used in the pipe zone should be capable of maintaining the specified soil density. For example, if a coarse material such as Class 1 is used for bedding the pipe, it should also be used in the haunch zone to the springline of the pipe. Otherwise, side support may be lost due to migration of the Class 2, 3 or 4 material into the bedding.

When selecting the embedment materials, ensure that native soil migration from the trench walls cannot occur. A well-graded compacted granular material will prevent this condition from occurring. In trenches subject to inundation, the granular material should be compacted to a minimum of 85% Standard Proctor Density.

Preparation of Trench Bottom

Preparation of the trench bottom is the starting point for a satisfactory and safe sewer pipe installation. The trench bottom should be smooth and free from large stones, clumps of dirt, and any frozen material as approved by the engineer. It is economical on most sewer installations to undercut the trench bottom by machine and bring it up to grade by use of granular material.

If the bedding material chosen is a loose granular such as sand, the pipe can be laid directly on it. If the bedding is a hard, compacted material, excavation for the bells (bell holes) should be provided so that the pipe is uniformly supported along the entire length.

Coarse sand, crushed stone or shell often is the most economical granular material because compaction is easily obtained. With all types of soil, voids should be eliminated under and around the lower half of the pipe by working in granular materials by shovel slicing.

Native backfill may be used for the trench bottom providing the soil is free of large stones, hard lumps and debris, and can be properly compacted by tamping. Ensure that the fill does not fit the Class 5 description.

In rocky trenches, place a minimum 100 mm (4") layer of select bedding material to provide a cushion for the pipe. The rock foundation must first be excavated to at least 100 mm (4") below the final grade of the pipe bottom. Any buried pipe, regardless of pipe material, that rests directly on rock may be subject to eventual breakage under the weight of soil and/or live loads.

When an unstable trench bottom is encountered and appears to be unable to support the pipe properly, the engineer may insist that the bottom be excavated and refilled to pipe grade with an approved foundation and bedding material. This layer should be compacted to a minimum 85% Standard Proctor Density.

Curved Sewers

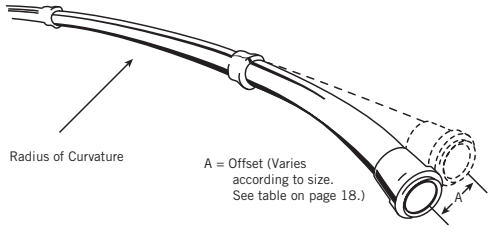
As a cost-saving alternative to manholes, gradual changes in direction for IPEX PVC Sewer Pipe may be achieved using one of the following:

a. bending the pipe (IPEX Ring-Tite and Enviro-Tite only)
b. deflecting the gasketed joint
c. using IPEX PVC fittings

A. Bending the Pipe Barrel

Smaller diameters of IPEX PVC Ring-Tite and Enviro-Tite Pipe up to 300 mm (12") diameter may be subjected to limited bending to follow the outline of a curved trench. This practice should not be attempted with Ultra-Rib or Ultra-X2 Pipe. The recommended procedure is as follows:

1. Make a concentric assembly in the usual way. Keep the spigot in straight alignment with the bell.
2. Place compacted backfill around the assembled joint to restrict its movement while the curvature is being made.



3. Place compacted backfill at the inside of the curve, at the mid-point of the pipe length, to form a fulcrum.
4. Using only manual effort, move the leading bell of the pipe length to be curved by no more than the offset distance shown in the following table.

Below is a table showing the minimum radius of curvature achieved by bending IPEX Ring-Tite and Enviro-Tite Pipe, and the resultant maximum offset for standard 4 m (13') lengths.

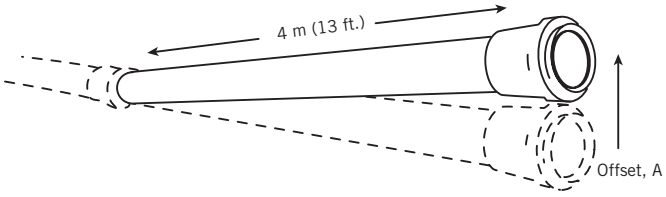
Pipe Size		Min. Radius of Curvature		Max. Offset, A	
mm	in.	m	ft.	mm	in.
100	4	14	46	570	22
125	5	18	59	450	18
150	6	20	66	400	16
200	8	27	89	300	12
250	10	34	112	235	9
300	12	40	132	200	8

Note: Bending is not recommended for Ring-Tite and Enviro-Tite pipe sizes greater than 300 mm (12") or for any size of Ultra-Rib or Ultra-X2 pipe.

B. Deflecting the Joint

The gasketed joints of IPEX PVC Sewer Pipe and Fittings are flexible enough to permit deviation in the assembled joint for directional changes. Below is the recommended procedure for curving a pipeline using joint deflection:

1. Make a concentric assembly, but push the spigot into the bell only to a point about 13 mm (1/2") short of the reference line. This type of assembly permits more movement of the end of the pipe at the neck of the bell.
2. Shift the loose bell end of the assembled length by not more than indicated in the following table.
3. This procedure should not be used in conjunction with Method A (bending the pipe barrel).



Below is a table illustrating the maximum allowable angle of deviation at the bell of IPEX PVC Sewer Pipe, as well as the resultant maximum offset for a standard 4 metre (13') length.

Pipe Size		Angle At One Bell	Maximum Offset, A		Radius Of Curvature	
mm	in.	degrees (°)	mm	in.	m	ft.
Ring-Tite and Enviro-Tite						
100 - 300	4 - 12	5	350	14	46	151
375 - 600	15 - 24	3	210	8	76	249
675 - 1050	27 - 42	1.5	105	4	153	502
Ultra-Rib						
200 - 600	8 - 24	5	350	14	46	151
Ultra-X2						
750 - 900	30 - 36	3	210	8	76	249
Centurion (20 ft. lengths)						
600 - 1200	24 - 48	1.5	160	6.25	233	764

Note: If half lengths of pipe are used, the above offset values must be divided by 2.

C. Using PVC Fittings

IPEX offers standard elbows and short or long radius sweeps in 11¼°, 22½°, 45° or 90°. PVC elbows can also be fabricated to any other angle configuration for all sizes of Ring-Tite, Enviro-Tite, Ultra-X2 or Ultra-Rib pipe. These fittings are assembled in the same manner as the pipe.

Sewer Laterals

In general, service laterals should be taken off at an angle of no greater than 45 degrees from the horizontal. This will minimize the effects of side-soil friction imposing excessive downward loads on the service connection.

When connecting laterals, use a long sweep PVC bend wherever possible to facilitate changes in slope more gradually. Good compaction is imperative beneath the long sweep bends as well as below the branch of the service connection in order to maintain proper soil support. The PVC long sweep bends from IPEX are made to a radius of curvature of six (6) times the nominal diameter of the bend.

Riser Problems Demand Special Attention

When vertical risers cannot be avoided consult the design engineer as more special precautions may be required.

Service lines from the property to the street sewer demand special design considerations when the collection sewer is deeper than 4 m (13') regardless of the piping material used. Service risers from main sewers buried more than 4 m (13') should be taken off at an angle not less than 45° from the vertical. The service should then be moved to the vertical position by an appropriate elbow and vertical section of pipe. In sanitary sewer systems, drop laterals and drop manholes are the most common examples of areas requiring this special attention.

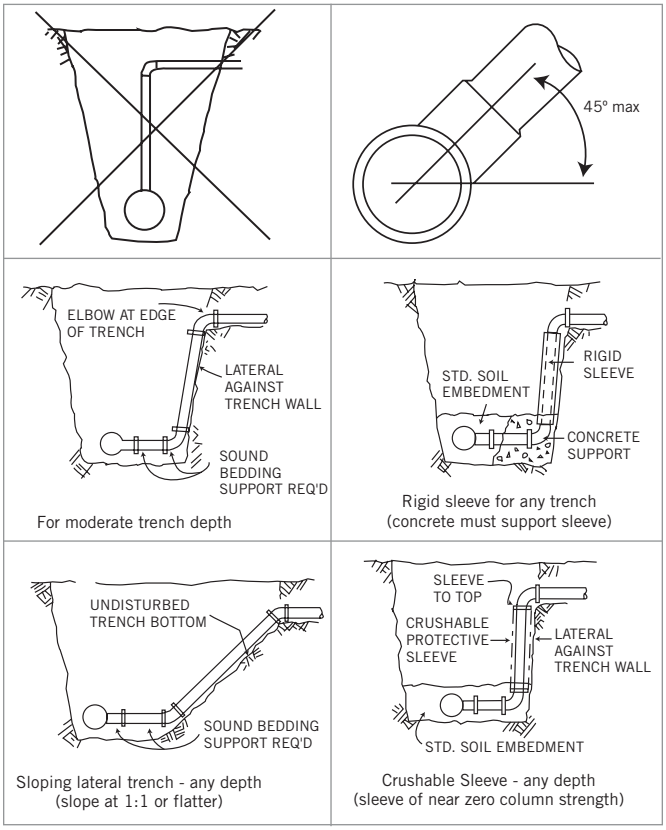
Drop laterals may create undue stresses on the buried pipe and fitting assembly. Horizontal portions of a lateral laid over disturbed uncompacted materials may experience a loss of bedding support if the foundation settles. This can lead to loss of grade and ultimately beam or shear failure in the pipe or fitting. As the soil adjacent to the pipe settles with the foundation, it attempts to drag the pipe with it, magnifying the load on the fittings.

Providing proper support beneath the mainline, service fitting, lateral, elevation fittings and their adjacent fill is critical. Since this is usually difficult, the best approach is to turn the lateral down immediately when entering the trench and keep it against the trench wall thus eliminating any unsupported portion.

Keeping the drop portion (and the upper elbow) immediately adjacent to the trench wall can reduce drag down effects and control beam bending during backfill. Even then, the elbow at the bottom must be both strong enough and bedded on a sound foundation to react to the loads. As depths increase, settlement loads can ultimately fail the system or buckle the riser.

Designs employing sleeves or concrete encasement of the drop portion of the lateral are effective if the designer provides an adequate means of supporting the loads at the bottom.

Sleeving the lateral with a crushable sleeve such as corrugated polyethylene drainage tubing can also solve the problem. As the fill adjacent to the lateral settles, the sleeve folds up and moves down with it. This accordion-like effect displaces the load from the lateral. It should be noted that when this method is used, the annular space between the sleeve and the lateral should not be filled with backfill.



Performance Testing of Sewer Installations

When specifying performance testing for installed sewers it is important to ensure that the complete system is tested. While a video inspection 30 days after installation is usually sufficient to identify any defects in the installation, there are a number of other performance tests that can be carried out.

One of the most useful tests is the low pressure air test, which is used to check the integrity of installed joints both for rigid pipes like reinforced concrete as well as PVC systems. IPEX recommends air testing for all installed sewer pipe, regardless of material, particularly when the pipe is installed in an area with a high water table.

Mandrel testing is generally only required whtn the video inspection shows significant defects with the installation and the pipe appears to be highly deflected (i.e. more than 7.5%).

Testing of Sewers

Joint Tightness Testing

To ensure the integrity of the assembled gasketed joints of a PVC sewer pipeline, often the designer will require testing after installation is complete. This testing is frequently a requirement for sanitary sewer lines and is a growing trend for storm sewer systems as well.

There are 2 options that may be specified by the designer to test joint tightness – Air Testing or Water Testing. Air testing is preferable where possible because of its accuracy, simplicity and minimal time consumption. Water testing tends to be more expensive than with air, but is advantageous in some situations.

1. Air Testing

Here, the installer must plug both ends of a section of sewer to be tested before subjecting that section of pipe to low pressure air. The air must be maintained at a minimum pressure of 24.0 kPa (3.5 psi) for the specified time period for each diameter shown in the table below. The maximum air pressure is 34.5 kPA (5.0 psi). Duration times vary with changes in pipe size and length of test sections. A maximum pressure drop of 3.5 kPa (0.5 psi) is permitted within the specified time duration. If a maximum pressure drop of 7.0 kPa (1.0 psi) is specified, the time values in the table should be doubled.

Should the pressure drop be greater than 3.5 kPa (0.5 psi) within the specified time duration, the deficiencies should be located and repaired. Re-testing must be performed until a successful test is achieved. Sources of leaks may be dirt in an assembled gasketed joint, incorrectly tightened

service saddles or improper plugging or capping of sewer lateral piping. If there is no leakage (i.e. zero pressure drop) after one hour of testing, the section should be passed and presumed free of defects.

If there is groundwater present at a level higher than the pipe invert during the air-test, the test pressure should be increased to a value of 24.0 kPa (3.5 psi) greater than the water head at the bottom of the pipe [to a maximum air test pressure of 34.0 kPa (5.0 psi)].

Pipe Size		Minimum Time	Length for Minimum Time		Time for Longer Meter Length	Time for Longer Feet Length
mm	in.	min:sec	m	ft.	sec	sec
100	4	1:53	182.0	600	0.623 L	0.190 F
150	6	2:50	121.3	400	1.401 L	0.427 F
200	8	3:47	90.8	300	2.493 L	0.760 F
250	10	4:43	72.8	240	3.894 L	1.187 F
300	12	5:40	60.7	200	5.606 L	1.709 F
375	15	7:05	48.5	160	8.761 L	2.671 F
450	18	8:30	40.5	133	12.615 L	3.846 F
525	21	9:55	34.7	114	17.171 L	5.235 F
600	24	11:20	30.2	100	22.425 L	6.837 F
675	27	12:45	26.8	88	28.382 L	8.653 F
750	30	14:10	24.4	80	35.040 L	10.683 F
900	36	17:00	20.1	66	50.472 L	15.384 F
1050	42	19:54	17.4	57	68.707 L	20.942 F
1200	48	22:47	15.2	50	89.736 L	27.352 F

where L = length of test section in metres
F = length of test section in feet

Example - If there is 0.5 metres (1.65 ft.) of water above the invert of a buried PVC sewer line, what must the air-test pressure be?

Solution - The static head of the groundwater at the pipe invert will be:

0.5 m x (9.73 kPa / m) = 4.87 kPa
therefore, the total air-test pressure should be:
4.87 kPa + 24.0 kPa = 28.87 kPa
or
1.64 ft. x (.43 psi / ft.) = .71 psi
therefore, the total air-test pressure should be:
.71 psi + 3.5 psi = 4.21 psi

Since this value is less than 34.0 kPa (5.0 psi), the installer may proceed with the air test using this start pressure.

Knowing the density of water to be 1000 kg/m^3 (62.4 lb/ft^3), the maximum head of groundwater permitted above the invert of a PVC sewer pipe for an air test is 1 metre (3.3').

2. Water Testing

Infiltration - The allowable infiltration for any pipe section should be measured by a weir or current meter placed in an appropriate manhole. This is an acceptable method of leakage testing only when the ground-water level is above the top of the pipe throughout the section of line being tested. It is especially useful when the water table is well above the top of the pipe. Usually the designer will give explicit instructions for conducting the test.

Exfiltration - This test is suitable for very dry areas, or where the water table is suitably low that test pressures can easily exceed the static head of the water table. Test pressures should be a minimum of 5.9 kPa (0.9 psi) above the water table head. The test section of pipe shall be filled with water and the leakage rate measured.

For sizes 100 mm - 375 mm (4" -15"), the allowable leakage rate shall be 4.63 liters per mm of pipe diameter per kilometer per 24 hours or 50 USgal./inch/mile/day. For sizes 450 mm (18") and larger, the allowable rate for testing shall be 0.93L/mm/km/day or 10 USgal./inch/mile/day. Should the allowable leakage rate be exceeded for either an infiltration or exfiltration test, the deficiency should be located and repaired. Tests are typically conducted from manhole to manhole.

Deflection Testing

Deflection is the way a flexible pipe reacts to vertical soil loads when buried in a trench. It illustrates how the pipe and surrounding soil work together to easily withstand common, and even extreme soil loads.

The maximum deflection of plastic pipe or fittings can be accurately predicted by the designer by knowing the pipe stiffness, soil stiffness and the height of cover. For the majority of underground PVC sewer pipe applications, with proper compaction, the deflection will be well within the recommended maximum allowable of 7.5%. However, if the designer has reason to believe that excessive deflection may be present, a deflection test may be necessary.

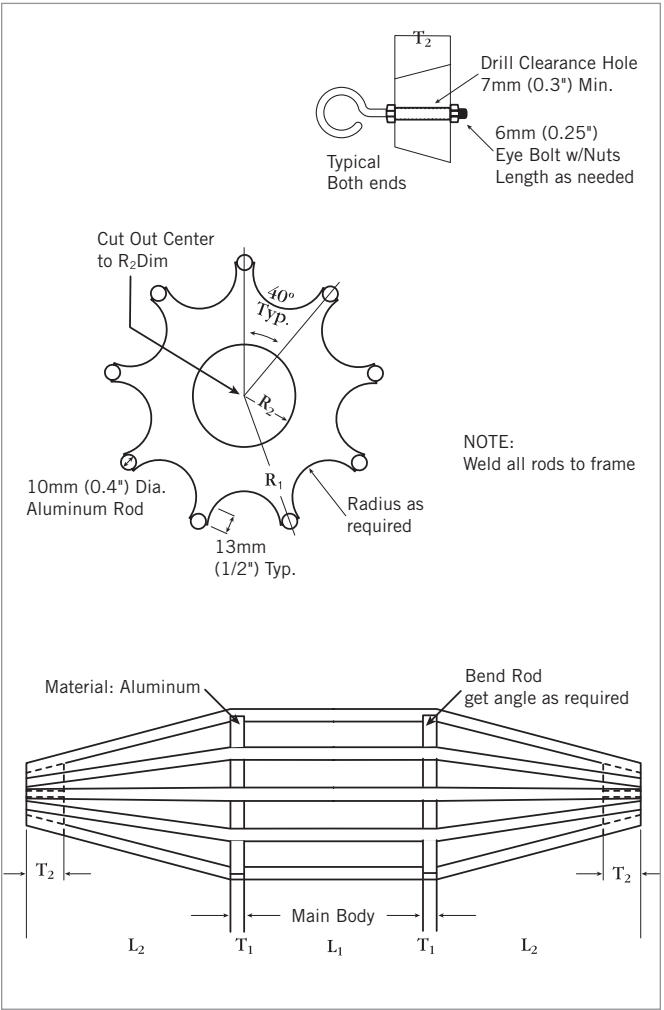
There are two commonly used methods of performing deflection tests on PVC sewer pipe:

1. Go-No-Go Device
2. Physical Measurement

1. Go-No-Go Device

The most popular method of the two is the rigid Go-No-Go mandrel. This gage can accurately determine whether the deflection is within specified limits. The test involves the pulling of a mandrel through an installed sewer line. The mandrel will simply get stuck if the actual deflection is beyond the specified limit (normally 7.5%). The mandrel must be designed to have dimensions which exactly match the clearance inside the pipe, at the deflection limit.

Below is a detailed drawing of a suggested mandrel design for 7.5% deflection, along with tables of appropriate dimensions for Ring-Tite, Enviro-Tite and Ultra-Rib Pipes.



Ring-Tite and Enviro-Tite - Mandrel Dimensions

Pipe Size		Base I.D.		L1, L2		R2		R1	
mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
200	8	194.7	7.67	150	6	35	1.4	90.0	3.54
250	10	242.9	9.56	200	8	40	1.6	112.3	4.42
300	12	288.6	11.36	200	8	45	1.8	133.5	5.26
375	15	353.0	13.90	230	10	50	2.0	163.3	6.43
450	18	431.2	16.98	300	12	55	2.2	199.4	7.85
525	21	508.1	20.00	300	12	60	2.4	235.0	9.25
600	24	571.0	22.48	350	14	65	2.6	264.1	10.40
675	27	643.3	25.33	350	14	70	2.8	297.5	11.71

Ultra-Rib - Mandrel Dimensions

200	8	196.1	7.7	150	6	35	1.4	91.2	3.6
250	10	245.2	9.7	200	8	40	1.6	114.0	4.5
300	12	291.8	11.5	200	8	45	1.8	135.7	5.3
375	15	357.3	14.1	230	10	50	2.0	166.1	6.5
450	18	438.7	17.3	300	12	55	2.2	204.0	8.0
525	21	515.8	20.3	300	12	60	2.4	239.8	9.4
600	24	584.2	23.0	350	14	65	2.6	271.7	10.7

Notes:

- T1 = 10mm (0.4") and T2 = 25mm (1") for all sizes of mandrels
- For pipes larger than 675mm (27"), physical measurement is recommended.
- Two times dimension R1 is critical passing dimension for deflection mandrels.

2. Physical Measurement

To begin this process, one must measure the vertical inside diameter at a particular point in a PVC sewer pipe before it is installed (D1). Next, measure the inside diameter at that same point after the pipe has been installed and completely backfilled (D2). Now, the deflection at that point can be computed as follows:

$$\text{Deflection} = \frac{D1 - D2 \times 100\%}{D1}$$

For accurate results, a micrometer should be used.

Videos

The use of video cameras to inspect the interior of newly installed sewer pipe is very common today. The idea of videotaping the inside of sewer lines was first conceived to fulfill the need to evaluate the decaying condition of older sewers made from traditional pipeline materials such as clay, brick or concrete. The only practical benefit of videos with regard to newly installed PVC sewer pipe is in detecting glaring installation deficiencies such as leaking joints or excessive deflections. Although videos are able to pinpoint the location of a deficiency, they are unable to quantify the magnitude of a problem or whether the deficiency is within allowable limits.

NOTES

SECTION THREE: APPENDICES

APPENDIX A: REFERENCES

1 Hulsman, Nowack; "70 Years of Experience with PVC Pipe", Conference Paper, Plastic Pipes XII, 2004

2 Moser, A.P., "Buried Pipe Design", 2nd Edition, 2001, pp.22

3 Spangler Handy, "Soil Engineering", 4th Edition, May 1982, pp.352

4 Uni-Bell PVC Pipe Association; "Handbook of PVC Pipe" 4th Edition, August 2001, pp.207

5 Hoogensen Metallurgical Engineering Ltd., "Examination of Submitted PVC Pipe Section", Report to IPEX, December 1998

6 Uni-Bell PVC Pipe Association; "Handbook of PVC Pipe" 4th Edition, August 2001, pp.359

APPENDIX B: CALCULATION RESULTS

Sewer Pipe Flows - Imperial Measure

Slope (ft/ft)	4" Ring-Tite & Enviro-Tite		6" Ring-Tite & Enviro-Tite		8" Ultra-Rib/ Ring-Tite/Enviro-Tite		10"Ultra-Rib/ Ring-Tite/Enviro-Tite		12" Ultra-Rib/ Ring-Tite/Enviro-Tite		15" Ultra-Rib Ring-Tite/Enviro-Tite	
	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s
0.001	1.0	0.1	1.3	0.2	1.6	0.5	1.8	1.0	2.1	1.6	2.3	2.7
0.002	1.4	0.1	1.8	0.4	2.2	0.8	2.6	1.4	2.9	2.2	3.3	3.7
0.003	1.7	0.1	2.2	0.4	2.7	0.9	3.2	1.7	3.5	2.7	4.1	4.6
0.004	2.0	0.2	2.6	0.5	3.1	1.1	3.6	1.9	4.1	3.1	4.7	5.3
0.005	2.2	0.2	2.9	0.6	3.5	1.2	4.1	2.2	4.6	3.4	5.2	5.9
0.006	2.4	0.2	3.2	0.6	3.8	1.3	4.5	2.4	5.0	3.8	5.7	6.5
0.007	2.6	0.2	3.4	0.7	4.2	1.4	4.8	2.6	5.4	4.1	6.2	7.0
0.008	2.8	0.2	3.7	0.7	4.4	1.5	5.2	2.7	5.8	4.4	6.6	7.5
0.009	3.0	0.3	3.9	0.7	4.7	1.6	5.5	2.9	6.1	4.6	7.0	7.9
0.010	3.1	0.3	4.1	0.8	5.0	1.7	5.8	3.1	6.5	4.9	7.4	8.3
0.020	4.4	0.4	5.8	1.1	7.0	2.4	8.2	4.3	9.2	6.9	10.5	11.8
0.030	5.4	0.5	7.1	1.4	8.6	2.9	10.0	5.3	11.2	8.4	12.8	14.5
0.040	6.3	0.5	8.2	1.6	9.9	3.4	11.5	6.1	12.9	9.7	14.8	16.7
0.050	7.0	0.6	9.2	1.8	11.1	3.8	12.9	6.8	14.5	10.9	16.6	18.7
0.060	7.7	0.7	10.0	1.9	12.2	4.1	14.1	7.5	15.9	11.9	18.1	20.4
0.070	8.3	0.7	10.9	2.1	13.1	4.5	15.2	8.1	17.1	12.9	19.6	22.1
0.080	8.9	0.8	11.6	2.2	14.1	4.8	16.3	8.6	18.3	13.8	21.0	23.6
0.090	9.4	0.8	12.3	2.4	14.9	5.1	17.3	9.2	19.4	14.6	22.2	25.0
0.100	9.9	0.9	13.0	2.5	15.7	5.3	18.2	9.7	20.5	15.4	23.4	26.4

Slope (ft/ft)	18" Ultra-Rib & Ring-Tite		21" Ultra-Rib & Ring-Tite		24" Ultra-Rib & Ring-Tite		27" Ring-Tite		30" Ring-Tite/ Ultra-X2		36" Ring-Tite/ Ultra-X2		42" Ring-Tite	
	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s	Full Velocity, ft/s	Full Flow Capacity, ft^3/s
0.001	2.7	4.6	3.0	7.0	3.3	9.8	3.5	13.3	3.8	19.1	4.3	30.8	4.8	45.9
0.002	3.8	6.5	4.2	9.9	4.6	13.9	5.0	18.8	5.4	27.0	6.1	43.6	6.8	65.0
0.003	4.7	7.9	5.2	12.2	5.6	17.0	6.1	23.0	6.7	33.0	7.5	53.3	8.3	79.6
0.004	5.4	9.1	6.0	14.1	6.5	19.6	7.0	26.6	7.7	38.1	8.7	61.6	9.6	91.9
0.005	6.0	10.2	6.7	15.7	7.3	21.9	7.9	29.8	8.6	42.6	9.7	68.9	10.7	102.7
0.006	6.6	11.2	7.3	17.2	8.0	24.0	8.6	32.6	9.4	46.7	10.6	75.4	11.7	112.5
0.007	7.1	12.1	7.9	18.6	8.6	25.9	9.3	35.2	10.2	50.5	11.5	81.5	12.7	121.5
0.008	7.6	12.9	8.5	19.9	9.2	27.7	9.9	37.6	10.9	53.9	12.2	87.1	13.5	129.9
0.009	8.1	13.7	9.0	21.1	9.8	29.4	10.5	39.9	11.5	57.2	13.0	92.4	14.4	137.8
0.010	8.5	14.4	9.5	22.2	10.3	31.0	11.1	42.1	12.1	60.3	13.7	97.4	15.1	145.3
0.020	12.0	20.4	13.4	31.4	14.5	43.8	15.7	59.5	17.2	85.3	19.4	137.7	21.4	205.4
0.030	14.7	25.0	16.4	38.5	17.8	53.7	19.2	72.9	21.0	104.5	23.7	168.7	26.2	251.6
0.040	17.0	28.9	18.9	44.5	20.6	62.0	22.2	84.2	24.3	120.6	27.4	194.8	30.3	290.5
0.050	19.0	32.3	21.2	49.7	23.0	69.3	24.8	94.1	27.2	134.9	30.6	217.8	33.8	324.8
0.060	20.8	35.4	23.2	54.4	25.2	75.9	27.2	103.1	29.8	147.7	33.5	238.6	37.1	355.8
0.070	22.5	38.2	25.0	58.8	27.2	82.0	29.4	111.3	32.1	159.6	36.2	257.7	40.0	384.3
0.080	24.0	40.8	26.8	62.9	29.1	87.6	31.4	119.0	34.4	170.6	38.7	275.5	42.8	410.8
0.090	25.5	43.3	28.4	66.7	30.9	92.9	33.3	126.2	36.4	180.9	41.1	292.2	45.4	435.8
0.100	26.9	45.7	29.9	70.3	32.5	98.0	35.1	133.1	38.4	190.7	43.3	308.0	47.9	459.3

Sewer Pipe Flows - Metric Measure

Slope (m/m)	100mm Ring-Tite & Enviro-Tite		150mm Ring-Tite & Enviro-Tite		200mm Ultra-Rib/ Ring-Tite/Enviro-Tite		250 mm Ultra-Rib/ Ring-Tite/Enviro-Tite		300mm Ultra-Rib/ Ring-Tite/Enviro-Tite		375mm Ultra-Rib RingTite/Enviro-Tite	
	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s
0.001	0.3	2	0.4	7	0.5	15	0.6	27	0.6	44	0.7	75
0.002	0.4	3	0.6	10	0.7	21	0.8	39	0.9	62	1.0	106
0.003	0.5	4	0.7	12	0.8	26	1.0	48	1.1	76	1.2	130
0.004	0.6	5	0.8	14	1.0	30	1.1	55	1.2	88	1.4	150
0.005	0.7	5	0.9	16	1.1	33	1.2	61	1.4	98	1.6	168
0.006	0.7	6	1.0	17	1.2	37	1.4	67	1.5	107	1.7	184
0.007	0.8	6	1.0	18	1.3	40	1.5	73	1.6	116	1.9	199
0.008	0.8	7	1.1	20	1.3	42	1.6	78	1.8	124	2.0	212
0.009	0.9	7	1.2	21	1.4	45	1.7	82	1.9	131	2.1	225
0.010	0.9	7	1.2	22	1.5	47	1.8	87	2.0	138	2.3	237
0.020	1.3	11	1.8	31	2.1	67	2.5	123	2.8	196	3.2	336
0.030	1.6	13	2.2	38	2.6	82	3.0	150	3.4	240	3.9	411
0.040	1.9	15	2.5	44	3.0	95	3.5	174	3.9	277	4.5	475
0.050	2.1	17	2.8	49	3.4	106	3.9	194	4.4	310	5.0	531
0.060	2.3	18	3.0	54	3.7	116	4.3	213	4.8	339	5.5	581
0.070	2.5	20	3.3	58	4.0	125	4.6	230	5.2	366	6.0	628
0.080	2.7	21	3.5	62	4.3	134	5.0	246	5.6	392	6.4	671
0.090	2.8	22	3.7	66	4.5	142	5.3	260	5.9	415	6.8	712
0.100	3.0	24	3.9	70	4.8	150	5.5	275	6.2	438	7.1	751

Slope (m/m)	450mm Ultra-Rib & Ring-Tite		525mm Ultra-Rib & Ring-Tite		600mm Ultra-Rib & Ring-Tite		675mm Ring-Tite		750mm Ring-Tite/ Ultra-X2		900mm Ring-Tite/ Ultra-X2		1050mm Ring-Tite	
	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s	Full Velocity, m/s	Full Flow Capacity, L/s
0.001	0.8	129	0.9	199	1.0	273	1.1	375	1.2	538	1.3	869	1.5	1299
0.002	1.2	182	1.3	282	1.4	386	1.5	530	1.7	761	1.9	1229	2.1	1837
0.003	1.4	23	1.6	345	1.7	473	1.8	649	2.0	932	2.3	1506	2.5	2249
0.004	1.6	257	1.8	399	2.0	546	2.1	750	2.3	1076	2.6	1738	2.9	2597
0.005	1.8	288	2.0	446	2.2	611	2.4	838	2.6	1203	2.9	1944	3.3	2904
0.006	2.0	315	2.2	489	2.4	669	2.6	918	2.9	1318	3.2	2129	3.6	3181
0.007	2.2	340	2.4	528	2.6	722	2.8	992	3.1	1423	3.5	2300	3.8	3436
0.008	2.3	364	2.6	564	2.8	772	3.0	1060	3.3	1522	3.7	2459	4.1	3673
0.009	2.4	386	2.7	598	3.0	819	3.2	1125	3.5	1614	3.9	2608	4.4	3896
0.010	2.6	407	2.9	631	3.1	863	3.4	1186	3.7	1701	4.2	2749	4.6	4107
0.020	3.7	576	4.1	892	4.4	1221	4.8	1677	5.2	2406	5.9	3887	6.5	5808
0.030	4.5	705	5.0	1092	5.4	1496	5.8	2054	6.4	2947	7.2	4761	8.0	7113
0.040	5.2	814	5.8	1261	6.2	1727	6.7	2371	7.4	3402	8.3	5497	9.2	8213
0.050	5.8	910	6.4	1410	7.0	1931	7.5	2651	8.3	3804	9.3	6146	10.3	9183
0.060	6.3	997	7.1	1545	7.6	2115	8.3	2904	9.0	4167	10.2	6733	11.3	10059
0.070	6.8	1077	7.6	1669	8.2	2284	8.9	3137	9.8	4501	11.0	7272	12.2	10865
0.080	7.3	1151	8.1	1784	8.8	2442	9.5	3353	10.4	4812	11.8	7774	13.0	11616
0.090	7.7	1221	8.6	1892	9.3	2590	10.1	3557	11.1	5104	12.5	8246	13.8	12320
0.100	8.2	1287	9.1	1994	9.9	2730	10.7	3749	11.7	5380	13.2	8692	14.6	12987

APPENDIX C: REFERENCE TABLES AND CONVERSION CHARTS

Table C-1	Weights of Water
Table C-2	Decimal & Millimeter Equivalents of Fractions
Table C-3	Volume Conversion
Table C-4	Pressure Conversion
Table C-5	Flow Conversion
Table C-6	Temperature Conversion
Table C-7	Length Conversion

TABLE C-1 WEIGHTS OF WATER

Units of Volume	Weight	
	pounds	kilograms
1 US Gallon	8.35	3.79
1 Imperial Gallon	10.02	4.55
1 litre	2.21	1.00
1 cubic yard	1,685.610	765.267
1 cubic foot	62.430	28.343
1 cubic inch	0.036	0.016
1 cubic cm	0.002	0.001
1 cubic metre	2,210.000	1,000.000

TABLE C-2 DECIMAL & MILLIMETER EQUIVALENTS OF FRACTIONS

Inches		Millimeters
Fractions	Decimals	
1/64	0.015625	0.397
1/32	0.03125	0.794
3/64	0.046875	1.191
1/16	0.0625	1.588
5/64	0.078125	1.984
3/32	0.09375	2.381
7/64	0.109375	2.778
1/8	0.125	3.175
9/64	0.140625	3.572
5/32	0.15625	3.969
11/64	0.171875	4.366
3/16	0.1875	4.763
13/64	0.203125	5.159
7/32	0.21875	5.556
15/64	0.23475	5.953
1/4	0.250	6.350
17/64	0.265625	6.747
9/32	0.28125	7.144
19/64	0.296875	7.541
5/16	0.3125	7.938
21/64	0.328125	8.334
11/32	0.34375	8.731
23/64	0.359375	9.128
3/8	0.375	9.525
25/64	0.390625	9.922
13/32	0.40625	10.319
27/64	0.421875	10.716
7/16	0.4375	11.113
29/64	0.453125	11.509
15/32	0.46875	11.906
31/64	0.484375	12.303
1/2	0.500	12.700

Inches		Millimeters
Fractions	Decimals	
33/64	0.515625	13.097
17/32	0.53125	13.494
35/64	0.546875	13.891
9/16	0.5625	14.288
37/64	0.578125	14.684
19/32	0.59375	15.081
39/64	0.609375	15.478
5/8	0.625	15.875
41/64	0.640625	16.272
21/32	0.65625	16.669
43/64	0.671875	17.066
11/16	0.6875	17.463
45/64	0.703125	17.859
23/32	0.71875	18.256
47/64	0.734375	18.653
3/4	0.750	19.050
49/64	0.765625	19.447
25/32	0.78125	19.844
51/64	0.796875	20.241
13/16	0.8125	20.638
53/64	0.828125	21.034
27/32	0.83475	21.431
55/64	0.859375	21.828
7/8	0.875	22.225
57/64	0.890625	22.622
29/32	0.90625	23.019
59/64	0.921875	23.416
15/16	0.9375	23.813
61/64	0.953125	24.209
31/32	0.96875	24.606
63/64	0.984375	25.003
1	1.000	25.400

TABLE C-3 VOLUME CONVERSION

Units of Volume	in^3	ft^3	yd^3	cm^3	m^3	liter	U.S. gal.	Imp. gal.
cubic inch	1	0.00058	-	16.387	-	0.0164	0.0043	0.0036
cubic foot	1728	1	0.0370	28,317.8	0.0283	28.32	7.481	6.229
cubic yard	46,656	27	1	-	0.7646	764.55	201.97	168.8
cubic centimeter	0.0610	-	-	1	-	0.001	0.0003	0.0002
cubic meter	61,023.7	35.31	1.308	-	1	1000	264.17	220.0
liter	61.02	0.0353	0.0013	1000	0.001	1	0.2642	0.22
U.S. gallon	231	0.1337	0.0050	3785.4	0.0038	3.785	1	0.8327
Imp. gallon	277.42	0.1605	0.0059	4546.1	0.0045	4.546	1.201	1

TABLE C-4 PRESSURE CONVERSION

Units of Pressure	atm	bar	lb/in^2	lb/ft^2	kg/cm^2	kg/m^2	inch H_20
atmosphere (atm)	1	0.987	0.068	-	0.968	-	0.002
bar	1.013	1	0.069	-	0.981	-	0.002
pound per square inch (psi)	14.7	14.5	1	0.007	14.22	0.001	0.036
pound per square foot (psf)	2,116	2,089	144	1	2,048	0.205	5.2
kilogram per square centimeter	1.033	1.02	0.07	-	1	0.0001	0.003
kilogram per square meter	10,332	10,197	703	4.88	10,000	1	25.4
inch of water (H_20) (4°C)	406.78	401.46	27.68	0.192	393.7	0.039	1
inch of mercury (Hg) (0°C)	29.921	29.53	2.036	0.014	28.96	0.003	0.074
inch of air (15°C)	332,005	327,664	22,592	148.7	321,328	32.13	816.2
foot of water (4°C)	33.9	33.46	2.307	0.016	32.81	0.003	0.083
foot of air (15°C)	27,677	27,305	1,883	13.07	26,777	2.678	0.006
millimeter of mercury (0°C)	760	750	51.71	0.36	735.6	0.074	1.868
millimeter of water (4°C)	10,332	10,197	703	4.88	10,000	1	25.4
kilopascal (kP)	101.3	100	6.89	0.048	98.07	0.01	0.249
Newton per square meter	-	-	-	0.021	-	0.102	0.004

Units of Pressure	inch Hg	inch air	ft H_20	ft air	mm Hg	mm H_20	kilopascal	N/m^2
atmosphere (atm)	0.033	-	0.029	-	0.001	-	0.01	-
bar	0.034	-	0.03	-	0.001	-	0.01	-
pound per square inch (psi)	0.491	-	0.434	0.001	0.019	0.001	0.145	-
pound per square foot (psf)	70.73	0.006	62.43	0.076	2.784	0.205	20.89	0.021
kilogram per square centimeter	0.035	-	0.03	-	0.001	-	0.01	-
kilogram per square meter	345.3	0.031	304.8	0.373	13.6	1	101.97	0.102
inch of water (H_20) (4°C)	13.6	0.001	12	0.015	0.535	0.039	4.015	0.004
inch of mercury (Hg) (0°C)	1	-	0.883	0.001	0.039	0.003	0.295	-
inch of air (15°C)	11,096	1	9,794	12	436.8	32.13	3,277	3.106
foot of water (4°C)	1.133	-	1	-	0.045	0.003	0.335	-
foot of air (15°C)	924.7	0.083	816.2	1	36.4	2.678	273.1	0.273
millimeter of mercury (0°C)	25.4	0.002	22.42	0.027	1	0.074	7.5	0.008
millimeter of water (4°C)	345.3	0.031	304.8	0.373	13.6	1	101.97	0.102
kilopascal (kP)	3.386	-	2.99	0.004	0.133	0.01	1	0.001
Newton per square meter	-	3.277	-	0.273	0.008	0.102	0.001	1

TABLE C-5 FLOW CONVERSION

Units of Flow Rate	US gps	US gpm	US gph	US gpd	Imp gps	Imp gpm	Imp gph	Imp gpd	liters/sec	liters/min	liters/hr	liters/day
US gal/sec (gps)	1	0.017	-	-	1.2	0.02	-	-	0.264	0.004	-	-
US gal/min (gpm)	60	1	0.017	0.001	72.06	1.2	0.02	0.001	15.85	0.264	0.004	-
US gal/hr (gph)	3,600	60	1	0.042	4,323	72.06	1.2	0.05	951.02	15.85	0.264	0.011
US gal/day (gpd)	86,400	1,440	24	1	103,762	1,729.40	28.82	1.2	22,824	380.41	6.34	0.264
Imperial gal/sec	0.833	0.014	-	-	1	0.017	-	-	0.22	0.004	-	-
Imperial gal/min	49.96	0.833	0.014	0.001	60	1	0.017	0.001	13.2	0.22	0.004	-
Imperial gal/hr	2,997.60	49.96	0.833	0.035	3,600	60	1	0.042	791.89	13.2	0.22	0.009
Imperial gal/day	71,943	1,199	19.98	0.833	86,400	1,440	24	1	19,005	316.76	5.279	0.22
Liters/sec	3.79	0.063	0.002	-	4.55	0.076	0.001	-	1	0.017	-	-
Liters/min	227.12	3.785	0.063	0.003	272.77	4.55	0.076	0.003	60	1	0.017	0.001
Liters/hr	13,627	227.12	3.785	0.158	16,366	272.77	4.55	0.189	3,600	60	1	0.042
Liters/day	327,060	5,451	90.85	3.785	392,782	6,546	109.11	4.55	86,400	1,440	24	1
Cubic ft/sec (cfs)	0.134	0.002	-	-	0.161	0.003	-	-	0.035	0.001	-	-
Cubic ft/min (cfm)	8.02	0.134	0.002	-	9.633	0.161	0.003	-	2.119	0.035	0.001	-
Cubic ft/hr (cfh)	481.25	8.02	0.134	0.006	577.96	9.63	0.161	0.007	127.13	2.119	0.035	0.001
Cubic ft/day (cfd)	11,550	192.5	3.21	0.134	13,871	231.18	3.853	0.161	3,051.20	50.85	0.848	0.001
Acre in/min	0.002	-	-	-	0.003	-	-	-	0.001	-	-	-
Acre in/hr	0.133	0.002	-	-	0.159	0.003	-	-	0.035	-	-	-
Acre in/day	3.182	0.053	0.001	-	3.821	0.064	0.001	-	0.841	0.001	-	-
Cubic m/sec	0.004	-	-	-	0.005	-	-	-	0.001	-	-	-
Cubic m/min	0.227	0.004	-	-	0.273	0.005	-	-	0.06	0.001	-	-
Cubic m/hr	13.628	0.227	0.004	-	16.366	0.273	0.005	-	3.6	0.06	0.001	-
Cubic m/day	327.06	5.451	0.091	0.004	392.78	6.546	0.109	0.005	86.4	1.44	0.024	0.001

Units of Flow Rate	ft^3/sec	ft^3/min	ft^3/hr	ft^3/day	Acre in/min	Acre in/hr	Acre in/ day	m^3/sec	m^3/min	m^3/hr	m^3/day
US gal/sec (gps)	7.48	0.125	0.002	-	452.6	7.54	0.31	264.2	4.4	0.073	0.003
US gal/min (gpm)	448.8	7.48	0.125	0.005	27,154	452.6	18.86	15,850	264.2	4.403	0.183
US gal/hr (gph)	26,930	448.83	7.481	0.312	1.629E+06	27,154	1,131	951,019	15,850	264.17	11.007
US gal/day (gpd)	646,317	10,772	179.53	7.481	3.910E+07	651,703	27,154	2.282E+07	380,408	6,340	264.17
Imperial gal/sec	6.229	0.104	0.002	-	376.8	6.28	0.26	220	3.67	0.061	0.003
Imperial gal/min	373.73	6.229	0.104	0.004	22,611	376.8	15.7	13,198	220	3.666	0.153
Imperial gal/hr	22,424	373.73	6.229	0.259	1.357E+06	22,611	942.1	791,889	13,198	220	9.165
Imperial gal/day	538,171	8,970	149.49	6.229	3.256E+07	542,656	22,611	1.901E+07	316,756	5,279	220
Liters/sec	28.32	0.472	0.008	-	1,713	28.6	1.19	1,000	16.67	0.278	0.012
Liters/min	1,699	28.32	0.472	0.2	102,790	1,713	71.38	60,000	1,000	16.67	0.694
Liters/hr	101,941	1,669	28.32	1.18	6.167E+06	102,790	4,283	3.600E+06	60,000	1,000	42.67
Liters/day	2,446,575	40,776	679.6	28.32	1.480E+08	2.467E+06	102,790	8.640E+07	1.440E+06	24,000	1,000
Cubic ft/sec (cfs)	1	0.017	-	-	60.5	1.008	0.042	35.31	0.589	0.01	-
Cubic ft/min (cfm)	60	1	0.017	-	3,630	60.5	2.52	2,119	35.31	0.59	0.025
Cubic ft/hr (cfh)	3,600	60	1	0.042	217,800	3,630	151.25	127,133	2,119	35.31	1.471
Cubic ft/day (cfd)	86,400	1,440	24	1	5.227E+06	87,120	3,630	3,051,187	50,853	847.55	35.31
Acre in/min	0.017	-	-	-	1	0.017	0.001	0.584	0.01	-	-
Acre in/hr	0.992	0.001	-	-	60	1	0.042	35.02	0.584	0.01	-
Acre in/day	23.8	0.033	0.006	-	1,440	24	1	840.55	14.001	0.233	0.001
Cubic m/sec	0.028	-	-	-	1.71	0.029	0.001	1	0.017	-	-
Cubic m/min	1.7	0.028	-	-	102.8	1.71	0.071	60	1	0.017	0.001
Cubic m/hr	101.94	1.7	0.028	0.001	6,167	102.8	4.283	3,600	60	1	0.042
Cubic m/day	2446.6	40.78	0.68	0.028	148,018	2,467	102.79	86,400	1,400	24	1

TABLE C-6 TEMPERATURE CONVERSION

°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
-60	-51	22	-5.6	50	10.0	78	25.6	160	71
-50	-46	23	-5.0	51	10.6	79	26.1	170	77
-40	-40	24	-4.4	52	11.1	80	26.7	180	82
-30	-34	25	-3.9	53	11.7	81	27.2	190	88
-20	-29	26	-3.3	54	12.2	82	27.8	200	92
-10	-23.0	27	-2.8	55	12.8	83	28.3	210	99
0	-17.8	28	-2.2	56	13.3	84	28.9	212	100
1	-17.2	29	-1.7	57	13.9	85	29.4	220	104
2	-16.7	30	-1.1	58	14.4	86	30.0	230	110
3	-16.1	31	-0.6	59	15.0	87	30.6	240	116
4	-15.6	32	0.0	60	15.6	88	31.1	250	121
5	-15.0	33	0.6	61	16.1	89	31.7	260	127
6	-14.4	34	1.1	62	16.7	90	32.2	270	132
7	-13.9	35	1.7	63	17.2	91	32.8	280	138
8	-13.3	36	2.2	64	17.8	92	33.3	290	143
9	-12.8	37	2.8	65	18.3	93	33.9	300	149
10	-12.2	38	3.3	66	18.9	94	34.4	310	154
11	-11.7	39	3.9	67	19.4	95	35.0	320	160
12	-11.1	40	4.4	68	20.0	96	35.6	330	166
13	-10.6	41	5.0	69	20.6	97	36.1	340	171
14	-10.0	42	5.6	70	21.1	98	6.7	350	177
15	-9.4	43	6.1	71	21.7	99	37.2	360	182
16	-8.9	44	6.7	72	22.2	100	37.8	370	188
17	-8.3	45	7.2	73	22.8	110	43	380	193
18	-7.8	46	7.8	74	23.3	120	49	390	199
19	-7.2	47	8.3	75	23.9	130	54	400	204
20	-6.7	48	8.9	76	24.4	140	60		
21	-6.1	49	9.4	77	25.0	150	66		

Degrees Celsius $°C = \frac{5}{9}(°F - 32)$ Degrees Fahrenheit $°F = \frac{9}{5}°C + 32$

Degrees Kelvin $°T = °C + 273.2$ Degrees Rankine $°R = °F + 459.7$

TABLE C-7 LENGTH CONVERSION

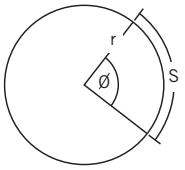
Units of Length	in.	ft.	yd.	mile	mm	cm	m	km
inch	1	0.0833	0.0278	-	25.4	2.54	0.0254	-
foot	12	1	0.3333	-	304.8	30.48	0.3048	-
yard	36	3	1	-	914.4	91.44	0.9144	-
mile	-	5280	1760	1	-	-	1609.3	1.609
millimeter	0.0394	0.0033	-	-	1	0.100	0.001	-
centimeter	0.3937	0.0328	0.0109	-	10	1	0.01	-
meter	39.37	3.281	1.094	-	1000	100	1	
kilometer	-	3281	1094	0.6214	-	-	1000	1

(1 micron = 0.001 millimeter)

APPENDIX D: USEFUL FORMULAS

- Area of a Circle
- Circumference of a Circle
- Length of Circular Arc
- Area of Circle Sector
- Equation of a Circle (cartesian coordinates)
- Equation of a Line (quadratic formula)
- Basic Trigonometric Functions
- Area of an Ellipse
- Circumference of an Ellipse
- Area of a Triangle
- Area of a Trapezoid
- Area of a Parallelogram
- Surface Area of a Sphere
- Volume of a Sphere
- Surface Area of a Cylinder
- Volume of a Cylinder
- Surface Area of an Elliptical Tank
- Volume of an Elliptical Tank
- Surface Area of a Cone
- Volume of a Cone
- Surface Area of a Rectangular Solid
- Volume of a Rectangular Solid

APPENDIX D: USEFUL FORMULAS



Circle

Diameter = $\frac{R}{2}$

Circumference = $\pi D = 2\pi R$

Area = πR^2

Length of Circular Arc

$S = Ø \times \left(\frac{\pi}{180}\right) \times r$ Ø in degrees

$S = Ø \times r$ Ø in radians

Area of Circle Sector

$A = \times \left(\frac{Ø}{360}\right) \times \pi \times r^2$ Ø in degrees

$A = \times \left(\frac{Ø}{2}\right) \times r^2$ Ø in radians

Equation of a Circle (cartesian co-ordinates)
for a circle with center (j, k) and radius (r)

$(x - j)^2 + (y - k)^2 = r^2$

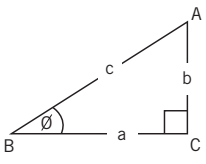
Equation of a line (quadratic formula)

$ax + by + c = 0$

or

$ax^2 + bx + c = 0$

$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$



Trigonometry

$\sin Ø = \frac{6}{c}$

$\cos Ø = \frac{9}{c}$

$\tan Ø = \frac{b}{a}$

Sine Law

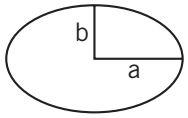
$$\frac{9}{\text{sinA}} = \frac{6}{\text{sinB}} = \frac{c}{\text{sinC}} = 2R$$

Cosine Law

$C^2 = a^2 + b^2 - 2ab \cos C$

$b^2 = a^2 + c^2 - 2ac \cos B$

$a^2 = b^2 + c^2 - 2bc \cos A$

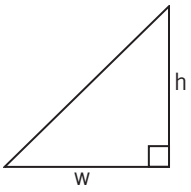


Ellipse

Area = $\pi \times a \times b$

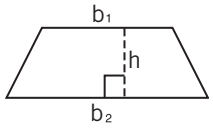
Circumference

$= \pi \left(3 (a + b) - \sqrt{(3a + b) (a + 3b)}\right.$



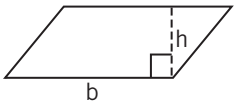
Triangle

Area = $\frac{w \times h}{2}$



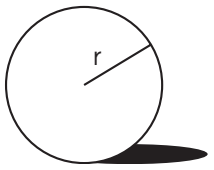
Trapezoid

Area = $\frac{1}{2}$ $(b_1 + b_2) \times h$



Parallelogram

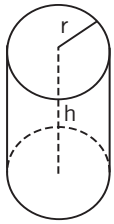
Area = b x h



Sphere

Surface Area = $4 \pi r^2$

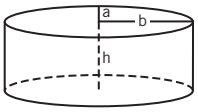
Volume = $\frac{4}{3}$ πr^3



Cylinder

Surface Area = $(2 \pi r^2) + (2 \pi r h)$

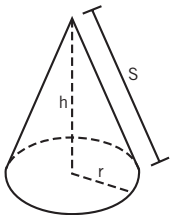
Volume = $\pi r^2 h$



Elliptical Tank

Surface Area = $2 \pi \left(\frac{\sqrt{a^2 + b^2}}{2} \right) h + (2\pi ab)$

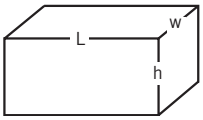
Volume = πabh



Cone

Surface Area = $\pi r S$

Volume = $\pi r^2 \times \frac{h}{3}$



Rectangular Solid

Surface Area = 2 (Lw + Lh + wh)

Volume = L x w x h

APPENDIX E: ABBREVIATIONS

AGA	American Gas Association
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BNQ	Bureau de Normalization du Quebec
BOCA	Building Officials and Code Administrators
BS	British Standards Institution
CPVC	Chlorinated poly (vinyl chloride) plastic or resin
CS	Commercial Standard, see Product Standard
CSA	Canadian Standards Association
DR	Dimension Ratio
DIN	German Industrial Norms
FHA	Federal Housing Administration or Farmers Home Administration
HDB	Hydrostatic design basis
HDS	Hydrostatic design stress
IAPD	International Association of Plastics Distributors
IAPMO	International Association of Plumbing and Mechanical Officials
IPC	International Plumbing Code
ISO	International Standards Organization
JIS	Japanese Industrial Standards
NSF	National Sanitation Foundation International
PPI	Plastics Pipe Institute
PS	Product Standard when in reference to a specification for plastic pipe and fittings. These specifications are promulgated by the U.S. Department of Commerce and were formerly known as Commercial Standards.
PSI	Pounds per square inch
PSIG	Gage pressure in pounds per square inch
PVC	Poly (vinyl chloride) plastic or resin
RVCM	Residual Vinyl Chloride Monomer
SCS	Soil Conservation Service
SDR	Standard Dimension Ratio
SI	International System of Units
SPI	Society of the Plastics Industry, Inc.
UPC	Uniform Plumbing Code
USASI	United States of America Standards Institute (formerly American Standards Association)
WOG	Water, Oil, Gas

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About the IPEX Group of Companies

As leading suppliers of thermoplastic piping systems, the IPEX Group of Companies provides our customers with some of the largest and most comprehensive product lines. All IPEX products are backed by more than 50 years of experience. With state-of-the-art manufacturing facilities and distribution centers across North America, we have earned a reputation for product innovation, quality, end-user focus and performance.

Markets served by IPEX group products are:

- Electrical systems
- Telecommunications and utility piping systems
- PVC, CPVC, PP, PVDF, PE, ABS, and PEX pipe and fittings
- Industrial process piping systems
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- Plumbing and mechanical piping systems
- Electrofusion systems for gas and water
- Industrial, plumbing and electrical cements
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