WHY CONCRETE PIPE?

The Pipe is Made of Concrete

Concrete is the world's most commonly used building material. In its simplest form, concrete is a mixture of paste and aggregates. The paste, composed of portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete.

Within this process lies the key to a remarkable trait of concrete: it's plastic and malleable when newly mixed, strong and durable when hardened. These qualities explain why one material, concrete, can build skyscrapers, bridges, sidewalks, superhighways, houses, dams, and precast storm and sanitary sewer pipe and boxes.

A properly designed concrete mixture will possess the desired workability for the fresh concrete and the required durability and strength for the hardened concrete. Typically, a mix is about 10 to 15 percent cement, 60 to 75 percent aggregate and 15 to 20 percent water. Entrained air in many concrete mixes may also take up another 5 to 8 percent.

Portland cement's chemistry comes to life in the presence of water. The character of the concrete is determined by quality of the paste. The strength of the paste, in turn, depends on the ratio of water to cement. The water-cement ratio is the weight of the mixing water divided by the weight of the cement. High-quality concrete is produced by lowering the water-cement ratio as much as possible without sacrificing the workability of fresh concrete. Generally, using less water produces a higher quality concrete provided the concrete is properly placed, consolidated, and cured.

Although most drinking water is suitable for use in concrete, aggregates are chosen carefully. Aggregates comprise 60 to 75 percent of the total volume of concrete. The type and size of the aggregate mixture depends on the thickness and purpose of the final concrete product. Almost any natural water that is drinkable and has no pronounced taste or odor may be used as mixing water for concrete. However, some waters that are not fit for drinking may be suitable for concrete. Specifications usually set limits on chlorides, sulfates, alkalis, and solids in mixing water unless tests can be performed to determine the effect the impurity has on various properties. A continuous gradation of particle sizes is desirable for efficient use of the paste. In addition, aggregates should be clean and free from any matter that might affect the quality of the concrete

Hydration Begins

Soon after the aggregates, water, and the cement are combined, the mixture starts to harden. All portland cements are hydraulic cements that set and harden through the chemical reaction with water. During hydration, a node forms on the surface of each cement particle. The node grows and expands until it links up with nodes from other cement particles or adheres to adjacent aggregates.

Curing begins after the exposed surfaces of the concrete have hardened sufficiently to resist marring. Curing ensures the continued hydration of the cement and the strength gain of the concrete. Concrete surfaces are cured by steam or water. The longer the concrete is kept moist, the stronger and more durable it will become. The rate of hardening depends upon the composition and fineness of the cement, the mix proportions, and the moisture and temperature conditions. Most of the hydration and strength gain take place within the first month of concrete's life cycle, but hydration continues at a slower rate for many years. Concrete continues to get stronger as it gets older.

Precast concrete products are cast in a factory setting. These products benefit from tight quality control achievable at a production plant. Precast products range from concrete bricks and paving stones to bridge girders, structural components, and panels for cladding. Precast concrete pipe is produced in highly controlled plant environments under rigid production standards and testing specifications.

Precast Reinforced Concrete Pipe is the Most Durable Drainage Product

Durability of a pipe material is as equally important as the ability of products made from that material to perform structural and hydraulic functions. The capability of pipe to perform as expected for the design life of a project is a fundamental engineering consideration, especially in today's economic environment where life cycle cost analysis and asset management requirements have been set in place to ensure sustainable buried infrastructure.

Durability is not defined as clearly as structural and hydraulic standards for drainage pipe systems, because it includes the performance of the components of concrete and reinforced concrete structures. Durability deals with life expectancy and the endurance characteristics of a material or structure. Among other considerations, the varying nature of climate, weathering, soils and geology, fluid chemistry, product installation techniques, in-plant production, material mixes and raw material quality cloud the development of a way to define durability and predict performance.

Durable is defined in Webster's New Collegiate Dictionary as, "able to exist for a long time without significant deterioration." Durability is defined by CSA (Canadian Standards Association) as, "The ability of a building or any of its components to perform its required function over an intended period of time." And, the ACI (American Concrete Institute) Committee 201 Durability of Concrete defines durability of portland cement concrete as, "The ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration."

Concrete is inherently a very durable material that will last indefinitely if it is designed properly for its intended environment and use, produced with good quality control, placed with sufficient care and expertise, and cured properly and thoroughly. Concrete is, however, potentially vulnerable to a variety of different deterioration mechanisms caused by adverse performance of paste, aggregates and steel.

Generally, surface attack of concrete is an extremely slow deterioration process. In most cases, aggressive agents must enter the concrete to cause significant damage. Permeability, diffusivity and absorption are the transport mechanism that allows such penetration. Permeability is the movement of gases or liquids through a porous medium due to a pressure head. Diffusivity is the transfer of mass by random motion of free molecules or ions in the pore solution due to a concentration gradient. Absorption is the transport of liquids in porous solids due to surface tension acting in capillaries.

The single parameter that has the largest influence on durability is the water/cement ratio (low water/cement ratios result in reduced permeability and increased strength). Permeability can be reduced by supplementary cementing materials, or chemical admixtures. Permeability will be increased by imperfect consolidation, excessive segregation, excessive bleeding, or drying cycles during curing. The single biggest factor causing increased permeability is cracking of the concrete.

Reinforced concrete pipe is a composite structure and specially designed to use the best features of both concrete and reinforcement. The concrete is designed for the compressive force and the reinforcement for the tensile force. Unless the concrete cracks, the reinforcement is not being used to its design capacity. As more tensile forces are carried by the reinforcement, hairline cracks become visible, but these occur at loads well below the design loading of the reinforced member. Hairline cracks are not an indication of danger, distress, or loss of structural integrity. Concrete pipe is generally designed to carry loads well within the engineered load bearing capacity of a pipeline, and hairline cracks do not occur. If hairline cracks do occur, they tend to seal themselves through a process known as autogenous healing. Autogenous healing is the ability of concrete to repair itself in the presence of moisture. Reinforced concrete pipe, unlike reinforced concrete beams and slabs, are buried where moisture conditions are present for autogenous healing to take place.

Corrosion of reinforcement involves an electrochemical attack mechanism on the reinforcing steel which results in a volume increase, thus inducing tensile stresses in the concrete. Structural concrete requires steel reinforcement to carry the applied tensile stresses. Concrete is normally capable of providing excellent protection to the steel and prevents it from corroding. This protection is both physical and chemical in nature. Physically**,** concrete restricts ingress of basic components required to initiate corrosion (water, oxygen, chlorides). Chemically, the pore solution in concrete typically has a very high pH, which leads to the formation of a protective iron oxide film around the steel reinforcement.

The primary physical reasons for lack or loss of protection by the concrete are insufficient cover over reinforcement, the presence of high permeability concrete, failure to protect concrete from chloride sources, and damage to concrete (cracking, spalling, scaling). Primary chemical reasons include penetration of chlorides into concrete, destruction of the passivation layer when chloride ion content reaches 0.2 percent to 0.4 percent in the region adjacent to steel. In addition, carbonation of concrete leads to a reduction in pH, then depassivation occurs as pH approaches 11.

Sulfate attack on concrete is a chemical reaction between an external source of sulfate ions and certain components of hexagonal close packing (hcp) at the molecular level. Detection of sulfate attack is very difficult due to its internal nature and minimal amount of visual damage. Though high levels of sulfates are present in seawater, sulfate attack is mitigated to some extent. Magnesium hydroxide chemically protects against sulfate attack, and gypsum and ettringite are more soluble in solutions containing chloride ions. Delayed Ettringite Formation (DEF) occurs when curing at elevated temperatures destroys ettringite, with the sulfate and aluminate being absorbed by the calcium silicate hydrate. After cooling, the sulfate is again available to form ettringite, resulting in expansion and cracking. This only occurs with certain cement chemistries and when moisture is readily available. It is a non-existing occurrence in the production of precast concrete pipe.

Acid attack is a chemical reaction between an external source of acidic liquid and hcp and, in some cases, aggregates. The attack is normally limited to the surface of concrete only, and may progresses inward. Dissolution of compounds soluble in the given acid takes place virtually instantaneously. In most cases, this reaction forms insoluble calcium salts which build up and protect the concrete from further attack.

Freeze/thaw damage to concrete is induced by internal tensile stresses which are a direct result of repetitive cycles of freezing and thawing. Freeze/thaw damage is through attrition - one cycle does very little damage. It takes many cycles before the damage adds up to significant levels. Contributing factors include expansion of water upon freezing (when volume increases nine percent), and hydraulic pressure. Freezing of water in concrete begins in larger cavities and progresses to successively smaller ones. This produces a hydrostatic pressure as the expansion forces unfrozen water ahead of the freezing front. The magnitude of hydrostatic pressure is a function of concrete permeability, distance to the void boundary, and the rate of freezing.

Surface wear is the progressive mass loss from a concrete surface due to repetitive attrition cycles. Abrasion is the dry attrition as another solid object moves along or rubs against the concrete surface. Erosion is surface wear caused by the abrasive action of solid particles suspended in fluids. It can occur on canal linings, spillways and pipes for water or sewage transport. Cavitation is the loss of mass caused by the formation of vapor bubbles and their subsequent collapse due to sudden changes of direction in rapidly flowing water.

Alkali-aggregate reaction is a chemical reaction between the soluble alkalis in hcp and certain forms of silica found in some aggregates. The time elapsed between concrete casting and the appearance of damage can vary significantly, depending upon the type of aggregate involved.

Concrete pipe Properties That Influence Performance

There are certain concrete properties that influence performance. These properties include concrete compressive strength, density, absorption, water/cement ratio, cementitious content and type, and aggregates.

Compressive strengths for concrete pipe normally range from 4,000 psi to 8,000 psi. It is a function of many factors including, aggregates, cementitious material, manufacturing, curing process and mix design. Most concrete design strengths refer to 28 day compressive strengths. It is not uncommon for 28 day tests to substantially exceed the specified design strengths.

Quality concrete pipe **densities** typically range from 145-155 pounds per cubic foot. Usually the higher the density, the greater the concrete "durability."

Absorption is primarily used to check the density and imperviousness of the concrete. As with compressive strength, the absorption can be greatly influenced by both the aggregates and the manufacturing process used. ASTM C 76 specifies a maximum allowable absorption of 8.5 percent or 9 percent, depending on the test method used, for concrete pipe.

Low water/cement (W/C) ratios are one of the trade marks of quality concrete pipe with corresponding high compressive strength as a function of the low W/C ratio. Typical precast concrete pipe have W/C ratios that range from 0.33 to 0.45 with 0.53 being the maximum allowed by ASTM C 76. Drycast concrete pipe using zero slump concrete allows immediate stripping of forms. Very dry precast concrete pipe using no slump concrete has a W/C ration of 0.20 that results in a compressive strength of 5000+ pounds per square inch (psi).

Cementitious content which has always been a topic of concern with engineers and manufacturers includes both cement and fly ash. The key to proper cementitious content is proper design of the mix, with consideration of all material properties, manufacturing and curing processes. All types of cement have been used in the manufacture of concrete pipe but generally Type II cement is used. Typical minimum cementitious content allowed by ASTM C76 is 5 sacks (470 lbs) per cubic yard of concrete.

Concrete pipe aggregates, both coarse and fine, meet the requirements of ASTM C 33 except for gradation. Both natural and manufactured aggregates are suitable for use in concrete pipe. Aggregates are a key element in producing quality concrete and in turn, quality pipe. With regards to strength, durability and performance, all aspects of the aggregates should be considered. These include gradation, absorption, specific gravity, hardness, and in some cases alkalinity.

There are many factors that influence the durability and performance of reinforced concrete structures that are well understood and managed to produce great structures that serve the Nation. Reinforced concrete pipe lasts for generations when it is designed properly for its intended environment and use, produced with good quality control, placed with expertise, and cured properly and thoroughly. When specifiers and design engineers understand the properties of concrete and all factors affecting the performance of reinforced concrete structures, durability of reinforced concrete pipe becomes meaningful. Only then can wise decision follow about matching service life of products to design life of structures.

References:
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<u>Concrete Pipe Is a Great Choice Based On Product and Material Performance</u>

Concrete pipe has a history of excellent performance as a durable product for sanitary sewer pipelines and storm water conveyance. The challenge is to know and understand the environment and service conditions that a sanitary or storm sewer would be subjected to, before it is designed and specified.

Concrete sewers continue to serve the Nation well, at a time when a majority of buried pipelines have reached the end of their planned service lives. It is concrete pipe sanitary and storm sewers (many produced and installed in the late 1800s), that continue to perform while funds are made available for their replacement and upgrade with new concrete pipe that is designed to last at least 100 years.

During the planning and design stage of a sanitary sewer, the potential biochemical profiles of the system should be determined along with current rates of acid development, and projected rates for the design life of the sewer. Once determined, the pipe can be protected with a liner. Pipe can also be produced with an increase in total alkalinity using calcareous aggregates. It is also common to increase the concrete cover over the reinforcement. Known as sacrificial concrete, the rate of deterioration of the system can be matched to the design life of the project.

Where acidic effluent is anticipated, designers need to determine the pH, including cyclic variations, as well as continuous or intermittent flow characteristics. The pH and total acidity for the design life of the system is critical. In addition, designers must determine the potential for the development of sulfuric acid due to potential changes to the environment of the interior atmosphere of the sewer. When highly corrosive environments are expected, consideration should be given to lined concrete pipe and manholes for the portions of the sewer expected to be affected.

Technology is now in place for making concrete pipe more reliable than it has ever been before. Decades of research and development of many aspects of concrete pipe has enabled concrete pipe producers to change concrete mixes and pipe design to provide products that can withstand a complete range of underground environments and effluent profiles. Our economy, societal values and international threats to the American way of life, have placed the application of concrete pipe in a new light.

Economic growth has taken on new meaning because of GASB 34, which radically changes how state and local governments must report their finances. Governments must perform condition assessments on all existing major infrastructure assets every three years. The National Cooperative Highway Research Program's project 19-04 states, "How state DOTs respond to GASB 34 may have a significant impact on statewide costs of public borrowing, the long-term costs of infrastructure programs, and the proportion of agency funds devoted to construction versus preservation."

The economic benefits of applying an asset management approach to public infrastructure reinforces the choice of concrete pipe for sustainable sanitary sewer systems. A sanitary sewer built today with low-maintenance reinforced concrete pipe (RCP) would last until 2100, if the system is planned and designed for 100 years with full knowledge of existing and future effluent characteristics and loading. When projects are designed with life cycle costs in mind, concrete pipe is truly a product that falls within the accepted general notion of sustainability by meeting the needs of the present generation, without compromising the needs of future generations.

Standard Installations alone are proving to be able to reduce the installation costs of construction projects significantly. For sewers that are expected to last 100 years or more, there is no doubt that a concrete pipe sanitary sewer would meet that target and likely keep on functioning for many more years. It only makes sense that concrete pipe be reconsidered in some states to enhance its infrastructure assets, and have concrete pipe reaffirmed as a 21st century technology in states that already use concrete for major sanitary sewer systems. Based on durability and performance, concrete pipe is the confident choice for sanitary and storm sewers.

Concrete Pipe Attributes

The main attributes of concrete pipe apply to sanitary, storm sewers and culverts. Many attributes also may be applied to box sections used for storm drainage, roadway culverts, tunnels, bridges, and underground detention systems. Concrete pipe and box sections accommodate great volumes of effluent in a tiny footprint.

Concrete pipe is known as a rigid pipe that provides both structure and conduit when it arrives on site. Flexible pipe systems including High Density Polyethylene and polyvinyl chloride (PVC) drainage systems provide conduit only. Backfill must be properly engineered and applied to provide structure. Imported fill is usually required for flexible pipe systems.

Concrete pipe is recognized for quality of manufacturing, consistent strength, availability in designs and sizes to serve most installations, being contractor friendly, and competitive with poured-in-place concrete structures and flexible pipe under many circumstances.

Concrete pipe produced in the early twenty-first century is a consequence of

- ✓ Computer aided design and analysis.
- ✓ Advanced concrete mix designs.

- ✓ Automated and computer controlled batching.
- ✓ Precision fabricated wire reinforcement.
- ✓ Quality driven manufacturing techniques.
- ✓ Improved water tight joints.
- ✓ New installation standards.

Precast concrete box section also have similar advantages to concrete pipe.

- ✓ Better quality control than flexible pipe products.
- ✓ Ease of installation.
- ✓ The dangers associated with open trenches are reduced.
- ✓ Reduced environmental impacts.
- ✓ Detour time is reduced.
- ✓ Design time is reduced
- ✓ Just-in-time delivery is available from producers' plants to accommodate small construction sites and tight construction schedules.
- ✓ Crews familiar with concrete pipe installation procedures can install box sections with minimal training.

<u>Inherent Strength</u>
Concrete pipe is a rigid pipe system that is over 85% dependent on the pipe strength and only 15% dependent on the strength derived from the soil envelope. The inherent strength of concrete pipe compensates for:

- ✓ Construction shortcomings.
- ✓ Higher fill heights and trench depths.

Concrete pipe is less susceptible to damage during construction, and maintains its shape, by not deflecting as does flexible pipe. Flexible pipe must deflect to reach its maximum installed performance. Flexible pipe is at least 95% dependent on soil support and the installation expertise of the contractor. This is the single most critical factor for using flexible pipe. Specifiers of flexible pipe products must consider design theory balanced against the practicality of installing the products in each application. Concrete pipe in comparison, has an unlimited range of pipe strengths from which to choose, and strength is demonstrated prior to installation. By specifying concrete pipe:

- ✓ The designer has more control over pipe strength than any other facet of the project.
- ✓ There is less reliance on quality installation by the installer.
- ✓ There is lower embedment material cost.
- ✓ There is less compaction required.
- ✓ It is easier to maintain grade and alignment.
- ✓ There are no excess deflection concerns.
- ✓ There is a lower life cycle cost of the project.
- ✓ There is a lower maintenance cost over the design life of the project.
- ✓ There is a reduced likelihood of failure.
- ✓ A lower risk for the specifier, designer and owner of the project, and reduced overall liability to the public after the project has been commissioned.

Concrete pipe strength is standardized by ASTM C76 and AASHTO M170. Pipe is strength-tested in the plant using D-Load standards. Supporting strength of a pipe is determined under three-edge-bearing test conditions. Expressed in pounds per linear foot per foot of inside diameter or horizontal span, D-load tests the pipe under severe loading conditions where there is no bedding, and no lateral support, under three-point loads.

ASTM C76 (standard for four classes of reinforced concrete pipe)

- ✓ Class I, II, III, IV, V
- ✓ Class III 1,350 lb/ft/ft
- ✓ Class IV 2,000 lb/ft/ft
- ✓ Class V 3,000 lb/ft/ft
- ✓ Gasketed joints are tested to 13 psi

ASTM C14 (non reinforced concrete pipe)

- ✓ Class 1, 2, 3
- ✓ D/Load expressed in lb/linear foot (to compare to reinforced divide by diameter)

Design Loading (used for determining pipe strength for installations underneath traveled roadways)

- ✓ AASHTO HS20 (Standard for vehicle loads on pipes)
    - 16,000 lbs Axle Load
    - 10” x 20” Tire Footprint
    - 0 - 30% Impact Load
    - Distributed 1.75H

Wire reinforcement in concrete pipe adds significantly to its inherent strength. Wire reinforcement shaped as cages is a precision-fabricated mesh fabricated by automatic cage welding machines. The cage machines fabricate machine formed bells, are dimensionally stable, and have close engineered tolerances. Reinforced concrete pipe have higher load capacities.

<u>Concrete Pipe Joints</u>

Concrete pipe offers a variety of joints from soil-tight to pressure. They are not affected by the type of backfill used for the installation. Joint performance must be demonstrated in the plant prior to pipe installation, and joint integrity can be field tested in a variety of ways. With concrete pipe, deflection will not compromise field joint test capability. The cross sectional rigidity of concrete pipe makes joint assembly a simple operation. Rigid joint integrity will minimize the likelihood of embedment intrusion and subsidence of overfill, often referenced as infiltration.

RCP joints withstand a minimum hydrostatic internal head of 13 psi equal to 30 feet of water. (ASTM C 443)

Types of concrete pipe joints include:

- ✓ O-Ring Gaskets.

- ✓ Profile Gaskets.
- ✓ Mortar Joint.

O Ring gaskets are used on all sanitary and some storm RCP produced with an O-Ring spigot joint. These gaskets are produced under ASTM designation C 443-94.

Profile gaskets are used on stormwater culverts and RCP storm and sanitary sewers. Pipe is produced with a single offset spigot joint according to ASTM designation C 443-94

Mortar Joints are used for storm sewers, culverts, and horizontal elliptical reinforced concrete pipe. Mortar is applied to the bottom half of the bell end.

Mastic and Butyl sealands are applied to the spigot or bell end of the pipe in accordance with ASTM designation C 990-96

In some applications, a mortar joint may be an external wrap applied to the external surface of the joint. These are applied in accordance with ASTM C 900-96.

<u>Concrete Pipe Mass</u>
In a low laying or marshy environment, the buoyancy of buried pipelines depends on the mass of the pipe material, the weight of the volume of water displaced by the pipe, the weight of the liquid load carried by the pipe, and the weight of the backfill material. Whenever the water table level is above the invert of the pipeline, the potential for floatation or buoyancy exists. Although the trench for a pipe installation in a marshy area is dewatered, the trench area downstream (after initial backfill) may become saturated. This would lead to a buoyant effect on the pipe. The mass of the concrete pipe typically counteracts this buoyant force. Alternate materials such as thermoplastic pipe and corrugated metal pipe may heave vertically or snake horizontally in wetland conditions. During the backfill operation, the fill may accumulate more on one side of the pipe than the other. The mass of the concrete pipe resists lateral forces, and the structure remains true to line and grade.

The mass of concrete pipe allows for:
- ✓ Effective compaction of embedment and backfill.
- ✓ Prevention of movement during backfilling ensures adherence to design grade and alignment.
- ✓ Unlikely movement of structure following installation.
- ✓ Reduces likelihood of floatation.
- ✓ Reduces possibility of damage during subsequent construction or maintenance in phased projects.

<u>Concrete Pipe is Non Flammable</u>
Unlike thermoplastic conduits, concrete pipe will not burn. This is important for the planning of road and highway cross drains in urban areas and remote locations that are heavily forested. Fires in culverts and sewers are well documented, demonstrating that

concrete pipe is a wise choice for construction site safety, public safety (fire and toxic fumes hazard), and homeland security.

Thermoplastic conduits are also sensitive to extremes in temperature that may cause joint separation, an impact on wall stiffness, and strains on the corrugations of some thermoplastic products.

Installation Made Easy At Least cost With Concrete Pipe

Standard Installations is a term for a new technology used for precast concrete pipe beddings. Design of the pipe wall - its thickness and amount of reinforcement - is based on the stresses and strains in the pipe. This approach is more precise and can result in pipes that require less material. In addition, the standard installations approach permits greater choice of backfill materials, from granular materials to clay, and needs less compaction of the backfill.

Standard Installations were adopted by the American Society for Civil Engineers (ASCE) as Specification 15-93-*Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations.* It was adopted later in the 1996 (16th) Edition of the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specification for Highway Bridges, Section 17, Soil-Reinforced Concrete Structure Interaction Systems.*

Standard Installations provide several benefits when using concrete pipe.

- ✓ Provides flexibility to meet design requirements and site conditions.
- ✓ Allows for narrower excavation limits.
- ✓ Less expensive backfill materials may be used.
- ✓ Can reduce the level of compaction.
- ✓ Increases contractor productivity in installing reinforced concrete pipe.

There is a choice of Types of Standard Installations that provide versatility to adapt to field conditions.

- ✓ Type 1**:** Highest Quality installation using select granular soils with high compaction requirements for haunching and bedding.
- ✓ Type 2**:** Allows silty granular soils with less compaction required for haunching and bedding.
- ✓ Type 3: Allows use of soils with less stringent compaction requirements for haunching and bedding.
- ✓ Type 4: Allows use of onsite native material for haunching and bedding with no compaction required. (6 inches of bedding is required if rock foundation)

The short lengths of concrete pipe makes it easier to work with around existing municipal services. Concrete pipe installations requiring trench boxes do not require special attention to sliding the trench box and disturbing the bedding and backfill in the process, referenced by all installation standards and recommendations of manufacturers. Using standard lengths of concrete pipe, line and grade can be checked frequently for accuracy.

Concrete Pipe Does Not Deflect or Deform
As a rigid pipe, concrete pipe has high beam strength and can be pushed to proper grade. Only concrete pipe can bridge over uneven bedding without affecting the pipe hydraulics. Flexible pipe has a low beam stiffness and deflects with uneven bedding, thereby inducing strain along the pipe axis.

Deflection testing of flexible pipe is critical to measure the strain and any circumferential deflection. Allowable deflection of flexible pipe is 3% initial and 5% long term. Deflection testing should not end, or be taken when backfilling has been completed. Installation problems not associated with concrete pipe, but may be associated with flexible pipe are deflection, deformation or buckling, wall strain or crush, and buckling. When installation or manufacturing failures occur with flexible pipe, there is often reduced hydraulic capacity of the drainage system and leaking joints. Mandrel testing of flexible pipe is mandatory in many jurisdictions.

Superior Hydraulics of Concrete Pipe
The hydraulic capacity (the amount of water a pipe can convey) of all types of pipe depends on the smoothness of the interior pipe wall. The smoother the wall, the greater the hydraulic capacity of the pipe. Smoothness of pipe is represented by Manning's Roughness Coefficient commonly called Manning's "*n*." The lower the Manning's "*n*" value, the greater the volume of water that will flow through pipe.

Hydraulic analysis for drainage systems involves the estimation of the design flow rate based on climatological and watershed characteristics. The hydraulic design of a drainage system always includes an economic evaluation. A wide spectrum of flood flows with associated probabilities will occur at the site during its design life. The benefits of constructing a large capacity system to accommodate all of these storm events with no detrimental flooding effects are normally outweighed by the initial construction costs. An economic analysis of the tradeoffs is performed with varying degrees of effort and thoroughness. Risk analysis balances the drainage system cost with the damages associated with inadequate performance. With concrete pipe, there is no risk. With its long service life and hydraulic efficiency, concrete pipe handles the requirements of a system's hydraulic design.

Two basic values are often cited when discussing the coefficient of roughness of a pipe; laboratory test values and design values. The difference between laboratory test values of Manning's '*n*' and accepted design values is significant. Manning's "*n*" values were obtained using clean water, smooth joints, no loads, and straight pipe lengths without bends, manholes, debris, or other obstructions. The laboratory results indicate only the differences between smooth wall and rough wall pipes. Rough wall, such as unlined corrugated metal pipe have relatively high "*n*" values, which are approximately 2.5 to 3 times those of smooth wall pipe.

Smooth wall pipes were found to have "n" values ranging between 0.009 and 0.010, but historically, engineers familiar with concrete pipe and sewers have used 0.012 or 0.013.

This design factor of 20 to 30 percent takes into account the differences between laboratory testing and actual installed conditions of various sizes as well as allowing for a factor of safety. The use of such design factors is good engineering practice, and to be consistent for all pipe materials, the applicable Manning's '*n*" laboratory value should be increased a similar amount to arrive at comparative design values.

Research has concluded that designs using concrete pipe can be downsized by at least one size in most cases when compared to steel, aluminum, and lined corrugated HDPE pipe. For design engineers and owners to select the proper drainage pipe for a specific culvert or sewer application, it is critically important that the applied Manning's "*n*" values are design values rather than laboratory values

Using design values, concrete pipe has superior hydraulic characteristics, and engineers understand and posses proper verification of concrete pipe hydraulics.

Grade and alignment are as important as barrel surface characteristics. In addition, inlet and outlet controls impact the hydraulics of a drainage system. The flow of water the pipe is throttled or limited by the inlet of the pipe. The inlet may have a headwall, flared end, or protruding pipe. This condition exists in most all crossdrains, and typical in subdivisions and county roadway crossings. Outlet control occurs when the flow of water through the pipe is controlled by the conditions at the outlet end of the pipe. Outlet control usually does not exist unless the outlet end of the pipe is under water or if the orifice has been damaged and restricted. The outlets of flexible pipe are easily damaged, thereby affecting the hydraulics of the pipeline.

Concrete pipe has more capacity to convey storm water than flexible pipe in many installed situations.

<u>Salvage Value of Concrete Pipe</u>
Pipelines, and in particular culverts, are often used in temporary applications to facilitate drainage during construction. While designers often try to minimize the cost of these facilities, one of the overlooked components is the salvage value of the pipe. Salvage value of pipe is closely related to its inherent strength and ability to survive the abuse of installation and removal. Flexible pipes show considerable wear and tear when removed after a temporary installation. The difficult task of digging up a buried culvert is complicated when heavy equipment is used to accomplish the job.

The rigid nature of concrete pipe is ideal for removal and replacement. Concrete pip is available to handle abuse of the type that would be expected in a removal job. In terms of life cycle costs, it is prudent to account for the salvage value of the pipe when planning a temporary line for drainage.

The benefit of salvaging concrete pipe does not stop on the construction site. There are projects where concrete pipe has been excavated in industrial areas after decades of use, cleaned and re-installed to continue performing as storm sewer pipe. The pipe was examined in laboratories and tested. It was found to be stronger that originally tested, as concrete does get stronger over time.

Quality Control and Testing of Concrete Pipe

The American Concrete Pipe Association offers an on-going quality assurance program. Called the "Quality Cast" Plant Certification Program, the 124-point audit-inspection program covers the inspection of materials, finished products and handling/storage procedures, as well as performance testing and quality control documentation. Plants are certified to provide storm sewer and culvert pipe or under a combined sanitary sewer, storm sewer, and culvert pipe program.

Included in the plant testing are:

- ✓ D-Load testing.
- ✓ Cylinder breaks.
- ✓ Hydro testing (offset joint test (under pressure).
- ✓ Vacuum testing or air testing.
- ✓ Joint sheer test.
- ✓ Spigot dimensional verification.
- ✓ Required certification / documentation on each delivery for:
  - Cement.
  - Fly Ash.
  - Steel.
- ✓ Freeze-thaw tests depending upon geography
- ✓ Certification on aggregates are required monthly.
- ✓ Required certification from supplier on gaskets. Gaskets also tested in plant for standards.
- ✓ Micrometer pallets and headers annually
- ✓ All testing and weighing equipment is calibrated and certified annually

Batching and mixing operations in the industry's premier plants have been upgraded over the past 10 years. Characteristics of this operation of the pipe production process normally include:

- ✓ Computer controlled weighing and proportioning systems.
- ✓ Computer controlled mixing systems.
- ✓ Automated recording systems
- ✓ Absorption testing

Concrete Pipe Cost

A least cost analysis is an effective method of evaluating two alternative materials with different service lives or economic equivalence. The factors which affect the traditional analysis are project design life, material life, first cost, interest rate, inflation rate, replacement costs, and residual value. First cost is important to the engineer and owner, but does not reveal the entire cost of the pipeline. Least cost analysis should also consider costs to the traveling public and businesses due to detours and replacement of potential catastrophic failures.

Flexible pipe products have lower "off-the-shelf" prices, but they are not as cost-effective as concrete pipe. Flexible pipe has a shorter service life, and requires premium bedding and backfill, installation procedures have to be precise for the bedding and backfill to take on the required structural characteristics, during and after installation inspection of flexible pipe systems is critical to performance, and mandrel testing is mandatory in many jurisdictions. In general, the true cost (installation, maintenance and replacement) of flexible pipe is twice that of concrete based on a 50-year or greater service life.

When flexible products are detailed and specified correctly, reinforced concrete pipe can compete favorably at the same or lower cost! Concrete pipe will not have to be replaced before the design life of a project has been reached. Concrete pipe is the strongest drainage product available, the most hydraulically efficient, and has great current and future value as an infrastructure asset.

Concrete Pipe Is An Environmentally Benign Material and Product

The choice to build drains, culverts and special stormwater management facilities with precast concrete is wise. Precast concrete drainage products are durable and installed quickly. They will not burn, corrode prematurely, deflect or move off grade to reduce hydraulic performance, or collapse under loads designed into the pipe structure. Comprised of the world's most commonly used building materials, precast concrete infrastructure is quickly integrated into ecosystems. This is clearly demonstrated by the use of three-sided precast boxes used to accommodate the natural channels of streams at road crossings, and precast concrete pipe for storm sewers and outfalls in valleys and shorelines.