Industry Innovations

Concrete Pipe and Monolithic Concrete Boxes

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Contents

LIST OF ABBREVIATIONS

Table A: List of Abbreviations

Abbreviation	Description
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACPA	American Concrete Pipe Association
ASCE	American Society of Civil Engineer
ASTM	American Society for Testing and Materials
BC	Before Christ
CAPE	Cost Analysis of Pipe Envelope
CPU	Concrete Pipe University
CSA	Canadian Standards Association
DOT	Department of Transportation
D.U.	Date Unknown
ENR	Engineering News-Record
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
LCA	Life Cycle Analysis
LRFD	Load and Resistance Factor Design
MIC	Microbial Induced Corrosion
NCHRP	National Cooperative Highway Research Program
PCI	Precast/Prestressed Concrete Institute
RCB	Reinforced Concrete Box
RCP	Reinforced Concrete Pipe
SCA	Slag Cement Association
SCC	Self-Consolidating Concrete
SCM	Supplementary Cementitious Materials
SIDD	Standard Installations Direct Design
SPIDA	Soil Pipe Interaction Design Analysis
VMA	Viscosity Modifying Admixtures
WWR	Welded Wire Reinforcement

INTRODUCTION

The word "innovative" has become quite a popular term in society, but what exactly is innovation and what is its impact on our market? Some synonyms that can be used in lieu of the word "innovative" are cutting-edge, advanced, state-of-the-art, inventive, and new. Like many words, the term "innovative" has had a dynamic definition throughout history. It wasn't until the 1900's that innovation became tied with market innovation. Since then, it has been thought of as a type of intellectual commodity; something that is required to increase economic efficiency and fuel progress. A basic definition of innovation could be, "A notable change in products or methods that creates new value in the form of convenience, quality, safety, cost savings, sustainability, or efficiency."

This document provides an in-depth look at the evolution of concrete pipe, citing notable changes in the design, manufacture, and installation methods that have been made to improve the product throughout the years. Readers will learn that, through proper and extensive engineering and testing, this "old" product has proven itself as rather innovative. Many of the innovations made throughout history are not easily recognized by the end user because they have resulted in very minimal changes to the product appearance, but instead have made impacts that compound over time and make the product better in every phase.

PHASES OF PRODUCT INNOVATION

If a product's innovation were to be broken down into phases and examined over its lifespan, one may consider the example model exhibited in Figure 1. As shown, innovation can be broken down into three basic phases: Invention, Upgrade, and Optimization. These phases are defined more clearly in Table 1. While this model attempts to evaluate innovation over the lifespan of a product, it is not an entirely clear depiction because it may be perceived differently from person to person and be represented differently from product to product. However, it still provides value in that it helps one understand that the term innovation has a wide-ranging and imprecise definition and perception among society. Notice that a level of risk has been established for each phase of innovation. A clearer description of the risks associated with innovation is provided in the sections below.

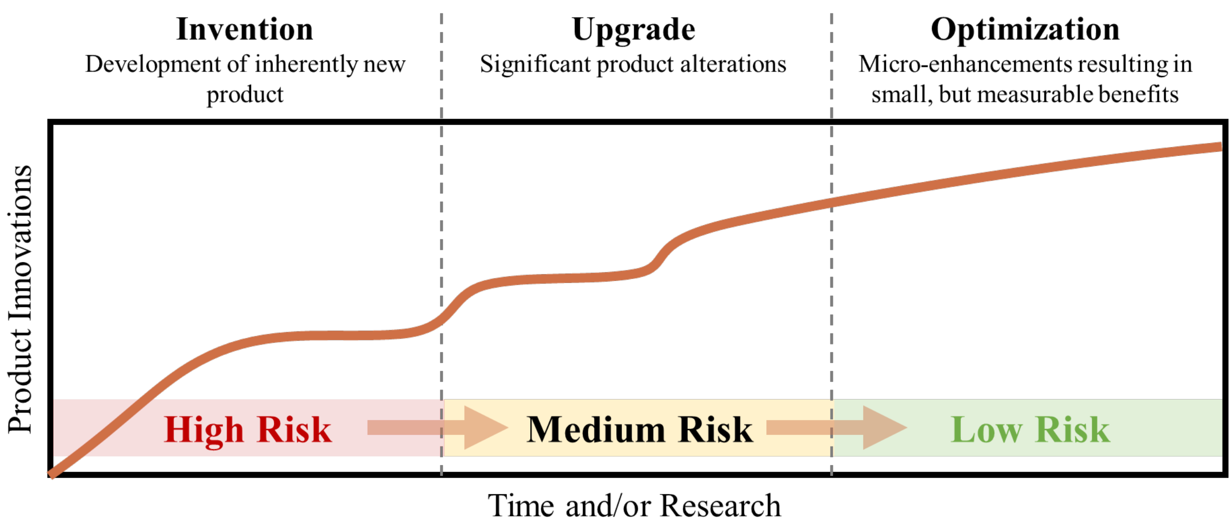

Figure 1: Phases of Innovation over Time

Table 1: Phases of Innovation

Innovation Phase	Description	Level of Risk
Invention	Development of a product that is inherently new without a comparable equal.	High
Upgrade	Significant alterations to an existing product that offers specific conveniences or user-efficiencies.	Medium
Optimization	Micro-enhancements to an existing product that provides improved end quality, lower costs, lesser environmental impacts, and/or decreased safety concerns.	Low

RISKS OF INNOVATION

Innovation has led to incredible inventions that have changed the way humans live and interact with each other. The push to invoke innovation in our market has had many notable impacts on society, but not all of these impacts have been positive. When innovation becomes a method to create profit it can turn into a target for corporations. Some corporations may strive to expedite the process of innovation in order to make a quicker revenue. This can have adverse effects on our market. The promotion of ideas and products purely because they are new can result in repercussions that may shift society from progression to regression.

An example of an innovation-gone-wrong could be the Samsung Galaxy Note 7. This cutting-edge device had many distinguished advancements from other cell phones on the market. It had an improved storage capacity, a larger screen, and better battery life. However, shortly after the release of this innovative product, it became most well-known for one of its disadvantages that was not accounted for before its release to the public. Its disadvantage was that it would spontaneously burst into flames and sometimes explode. Many consumers suffered the repercussions of Samsung's strive for developing the most innovative cell phone on the market. Soon, Samsung was forced to recall all that were sold.

Depending on one's perception, the development of the Note 7 could fall into almost any of the three phases of innovation. One may consider the Note 7 as an entirely new invention simply because there were properties of the product that were unlike any other products that existed. Another may claim that the Note 7 would fall into the Upgrade phase of innovation because, while the product had many alterations, it was still a cell phone and cell phones had already been invented. Finally, someone else may consider the alterations of the Note 7 to be minor enhancements and may claim that it would fall into the Optimization phase of innovation. The variation in how innovation is understood from person to person indicates again that innovation has a wide-ranging and imprecise perception among society.

Another example of innovation-gone-wrong was an apparent improvement to one major aircraft manufacturer's primary fleet. This new and inventive aircraft design utilized a larger engine that would allow for fuel savings while also maintaining the same functioning design to permit minimal pilot training prior to operation. While the intention of the new design was to create economic efficiencies, the race for profit led to many oversights in safety and resulted in an irresponsible advancement. The consumer repercussions of the Galaxy Note 7 were property damage and non-fatal human injuries such as burns. However, the repercussions of the aircraft's innovation were fatal and resulted in the death of hundreds of people.

While innovation has resulted in many incredible advancements, accelerating innovation can result in unforeseen disadvantages that could have major repercussions. Certain attributes such as research and time can play an important role in the level of risk associated with a product's innovation.

High Risk Innovations

For example, consider a product that is invented, upgraded, and optimized in a relatively short amount of time or with little research. Products that undergo many alterations in relatively short time frames or with minimal research should be considered as high-risk products. This can be justified in multiple ways. First, each alteration to a product poses its own unforeseen risks that are exposed as the product is utilized over time. Second, when a product is changed from its prior design, it could signify that the prior design had unforeseen disadvantages that required adjustments.

Note that when a product is in the invention phase, the level of societal risk is relatively high. This implies that when a product is first invented, it is nearly impossible to accurately account for all potential disadvantages of that product due to its short time of existence. As a product proceeds to exist over time, disadvantages of the product are uncovered. Many new products may be discontinued after development in the invention phase due to extreme unforeseen disadvantages of the product's implementation.

Low Risk Innovations

Some products that are invented may experience minimal to no changes over long periods of time. Products with widespread use in society that have relatively long timeframes in the x-axis of Figure 1 can be considered low risk products because, as time of use becomes greater, most disadvantages of that product are exposed and accounted for.

However, products that have longer lifespans do not always correlate to low risk for consumers. An example of a product that had extreme unforeseen disadvantages while also having a relatively long lifespan is Freon, a refrigerant that was invented and marketed as a "miracle compound" in 1928. Freon was intended to be a safe alternative to the toxic and dangerous refrigerants then in use such as ammonia, methyl chloride, and sulfur dioxide. It wasn't until the late 1970's, more than 40 years after its invention, that Freon was discovered to have caused extreme destruction to the ozone layer, allowing for higher levels of genetically harmful ultraviolet radiation to enter into the Earth's atmosphere and pose great threats to the environment and all that live within it. Freon was eventually banned for use in new systems by the Environmental Protection Agency (EPA) in 2010 with a goal to completely stop production in 2020 (EPA, 2020).

It is not always possible to prevent unforeseen disadvantages of new products from having extreme negative impacts on society. However, it may prove advantageous to exercise caution, and perhaps implement restrictions, of full-scale implementation of newly invented products or materials for high-stake and widely prominent uses such as infrastructure until proper research has been conducted to uncover potential disastrous societal repercussions of the product. Similarly, it may also prove advantageous to encourage the use of well-researched materials and products that have had widespread uses throughout history.

THE IMPORTANCE OF RESPONSIBLE INFRASTRUCTURE INNOVATIONS

Innovation is an important element of society that can be used to fuel progress. It has resulted in breakthroughs such as electricity, telephones, automobiles, and airplanes. However, if innovation is not done responsibly and with the correct research and testing prior to implementation, it can have disastrous results. This is true for innovations of all types, but perhaps one of the most important areas which should require responsible and well-planned innovation is our infrastructure. This is because changes in our infrastructure impact everyone.

Infrastructure is the foundation of our society. The advancement of poorly researched infrastructure materials could have an extreme negative impact on all other societal advancements. It should be of utmost concern to the people to ensure that innovations in infrastructure shall be done with great care and responsibility and that new materials should undergo extensive research before being implemented as standard.

INNOVATIONS IN PRECAST CONCRETE PIPE & STRUCTURES

An example of a material that has undergone extensive research throughout history is concrete. Concrete has been utilized as a building material for over 8,500 years with its earliest recorded concrete structures dating back to 6500BC in regions of Syria and Jordan (Pepin, 2017). Since its invention, there have been countless upgrades and optimizations to its design and use. Each of these optimizations have improved concrete's ability to serve the ever-changing needs of society. As an extremely versatile building material, concrete has been utilized in many ways to make many different infrastructure elements. Some particular products made with concrete are precast concrete pipe and monolithic concrete boxes. This paper will outline innovations that have occurred in the following categories throughout the existence of concrete pipe in America:

- *Concrete Mix Designs*
- *Reinforcement*
- *Joints*
- *Production & Quality*
- *Standards & Design Aids*
- *Installation*
- *Research*

Included in this report is an overview of all innovations to date, regarding the topics discussed within the report. The Innovations Overview Table following the section content includes key advancements ordered sequentially regarding that section topic. Furthermore, Appendix A provides a table that shows all innovations discussed within this document in sequential order.

CONCRETE MIX DESIGNS

With concrete being the most commonly used construction material in the world, many material advancements have been developed over time that have resulted in an overall improvement of concrete products across the board. Furthermore, new concrete ingredients and innovative concrete mix designs continue to be developed to this date which broadens the versatility of concrete, allowing for a wider range of product benefits and applications for the end user such as improved technical, economical, and environmental advantages. This section of the document will describe some alternative concrete ingredients, beyond aggregates, water, and cement that have resulted in advancements of the concrete industry. This section will also describe improvements made to conventional wet cast, dry cast, and self-consolidating concrete (SCC), that have made extreme positive impact on precast concrete pipe production.

ALTERNATIVE CONCRETE INGREDIENTS

Alternative concrete ingredients have allowed for highly customizable and versatile concrete mix designs that can provide a variety of benefits for concrete pipe such as improved production rate, safety, sustainability, aesthetics, product cost, and service life. However, these ingredients have not always been available for use in concrete mixes. In fact, it wasn't until the mid- and late-twentieth century that many of these alternative ingredients were discovered to have value in concrete production. Most alternative concrete ingredients can be divided up into one of two categories, *chemical admixtures,* and *supplementary cementitious materials (SCM)*. Table 2 includes a variety of alternative concrete ingredients including several chemical admixtures and supplementary cementing materials that have been used in the concrete pipe and box section industry.

Admixtures

An admixture in concrete is defined in American Concrete Institute (ACI) 116R as "a material other than water, aggregates, hydraulic cement, and fiber reinforcement, used as an ingredient of concrete or mortar, and added to the batch immediately before or during its mixing" (ACI, 2000). Admixtures such as water reducers, retarders, accelerators, and air-entraining agents started being used significantly in concrete mixes in 1950's (Harris & Jeknavorian, 2014), but it was not until the mid-1970's when a widespread admixture use in concrete pipe kicked off (*Washabaugh, 2020). If used properly, chemical admixtures can provide a variety of benefits to both pre-cure concrete properties, such as workability, setting time, and segregation, as well as post-cure concrete properties such as strength, durability, and resistance to degrading environments. These benefits are passed on to the product end users in the form of expedited product availability, improved quality, and extended service life.

Supplementary Cementitious Materials

An SCM is an inorganic material that aids the properties of cement through hydraulic or pozzolanic activity, or both (Suttor, 2016). SCM's have been used throughout history. However, it wasn't until the mid to late 1900's when research picked up and the modernization of SCM's began making significant traction in North America (Kosmatka et al., 2002). Among many improved concrete product properties, such as higher strength, durability, and chemical resistance, the use of SCM's in precast concrete allows for environmental advantages by promoting the use of recycled materials, as well as by replacing a portion of the required cement content and thus reducing cement's carbon footprint. Using SCM's in concrete mixes appropriately can allow for reduced maintenance, longer service life, and lowered costs. Some of the most commonly used SCM's in concrete pipe are fly ash and slag cement.

Research and development of alternative concrete ingredients has provided infinite variations of innovative and versatile concrete mix designs. Any newly developed mix design has the potential to create a paradigm shift in the understanding and overall use of concrete. Table 2 provides a list of common alternative concrete ingredients along with their desired effect and earliest known date of use in North America. Since discovery, each ingredient described in Table 2 has undergone extensive research and development which has fine-tuned and will continue to fine-tune its potential benefits. Application of the various admixtures discussed in this report must be verified through testing to be compatible with and produce the desired result for concrete pipe. For more information on which alternative concrete ingredients may be acceptable for use in concrete pipe, consult with your local concrete pipe manufacturer.

Table 2: Alternative Concrete Ingredients (Kosmatka et al., 2002)

Material	Desired Effect in Concrete Mix	First Use in North America
Accelerators	Accelerate setting and early-strength development	Unknown
Air-entraining admixtures	Improve workability and durability in freeze-thaw climates	1932 (*Washabaugh, 2020)
Bonding admixture	Increase bond strength	Unknown
Coloring admixture	Colored concrete	1927 (*Washabaugh, 2020)
Corrosion inhibitors	Control steel corrosion	1979 (Harris & Jeknavorian, 2014)
Damp and water proofing admixtures	Slow moisture penetration into dry concrete	1927 (*Washabaugh, 2020)
Hydration control admixtures	Control setting	1986 (*Washabaugh, 2020)
Permeability reducer	Decrease permeability	Unknown
Retarding admixture	Extend setting time	1932 (*Washabaugh, 2020)
Shrinkage reducers	Reduce drying shrinkage	1996 (Harris & Jeknavorian, 2014)
Lubricants and surfactants	Reduce surface friction, improve vibration reaction & moisture retention (ACPA, 2015)	Unknown
Superplasticizers	Increase flowability and reduce water-cement ratio	1975 (Levy, 2012)

Water reducer	Reduce water content at least 5%	1932 (Roberts, 2018)
Mid-range water reducer	Reduce water content (between 6 and 12%)	1984
High-range water reducer	Reduce water content (minimum 12%)	1975 (Levy, 2012)
Viscosity modifying admixtures (VMA)	Alters viscosity, workability, and cohesiveness (Anupoju, 2018)	1997 (*Washabaugh, 2020)
Fly Ash	Cementing material used to increase durability and strength	1930's
Slag Cement	Cementing material used to increase durability and strength	Early 1900's

CONCRETE PIPE AND BOX SECTION MIX DESIGNS

There are several methods for producing concrete pipe and boxes; the mix designs though can be separated in two main categories; dry and wet cast. Dry cast or zero slump mix is placed in some type of form and the form is almost immediately removed after the mix is compacted, while in the wet cast production a higher slump mix is placed in a form and the form cannot be removed until the product reaches an initial required strength. In both cases, raw materials are combined in a systematic manner, using quantities and proportions specially designed for the final application of the product while considering material availability and compatibility. The quality of precast concrete mix designs is obtained from sophisticated processes and equipment integrated under controlled conditions. While a number of different methods are used, each is capable of producing precast concrete pipe and monolithic concrete boxes that conform to requirements of specified standards. It is recommended to consult with local producers for specific project requirements.

Wet Cast Concrete

The first nonreinforced concrete pipe installed in the United States was in 1842 in Mohawk, New York and was produced with wet cast concrete (ACPA, 1981). Wet cast concrete is the mix that the general public has known for ages. To those not familiar with wet cast mixes, it is what is thought of when we hear the word “concrete”. Dating back to the Romans, wet cast concrete may have been considered a new and innovative construction material; however, due to its age and extensive use through the years, it is often overlooked as such. Nevertheless, using of various alternative concrete ingredients as mentioned above, wet cast concrete been innovated through the years to enhance performance characteristics over a wide range of applications. Manufacturers of precast concrete pipe and other structures use the various mix designs to improve efficiencies, constructability, and quality of their products. The mixes can be designed for high-early strength in order to accommodate market demands, or for increased flow to aid in concrete placement in certain structures and form equipment.

Dry Cast Concrete

A definition of dry cast concrete, can be found in ASTM C1837, as “a very low slump or zero-slump concrete that requires continuous and intense vibration, or mechanical means, or a combination of vibration and mechanical meant to consolidate the concrete, enabling immediate removal of the forms from the product.” The first installation of dry cast reinforced concrete pipe in the United States was in 1906. These pipes were made by placing circular rings of reinforcement into the forms as a dry mix concrete was tamped by hand until the concrete was compacted around the reinforcement (ACPA, 1981; *Washabaugh, 2020). Through the years, advancements of automated machines for packing, vibration, and curing has allowed for a quicker production since forms can be removed immediately after proper compaction. This enables continuous production since the same form can be used throughout the day. Overall, the use of dry cast concrete allows for a speedy production rate and optimal use of plant footprint and resources. This benefits the end user by enabling producers to meet demands of tight schedules and fast deadlines.

Self-Consolidated Concrete (SCC)

Water reducing admixtures have experienced immense development over time which has ultimately led to a major innovation in wet-cast concrete, SCC. According to ACI Committee 237, SCC is a highly flowable, non-segregating concrete that can flow in the formwork and through the reinforcement under its own weight and without any mechanical consolidation (ACI, 2007; Lemay, 2019; FHWA, 2005). SCC was first developed in 1986 by Professor Okamura at Ouchi University, Japan (Lemay, 2019). Since its development, organizations such as Precast/Prestressed Concrete Institute (PCI), American Society for Testing and Materials (ASTM) and ACI began working on SCC’s approval to their standards. While the applicability of SCC must be evaluated on a plant-by-plant basis based on numerous criteria including material compatibility and local specifications, one of the most impactful benefits of using SCC in precast concrete operations is the elimination of vibratory compaction which allows for safer and more sustainable production. SCC also allows an increase in the precast factory’s automation which in turn leads to improved worker productivity and product quality while at the same time provides the same or better plastic and hardened properties when compared to conventional concrete (Tripp, 2018).

Concrete mix designs have seen a plethora of inventions, upgrades, and optimizations throughout history with a main focus on being effective in regards to time, economics and raw material availability while maintaining or improving product quality and service life. Materials and proportioning techniques combined are continuously investigated to meet the increased demands for sustainable and resilient products that can be delivered on time while being cost effective.

Table 3 below provides a general overview of key advancements in the precast concrete industry regarding concrete mix designs.

Table 3: Concrete Mix Design Innovations Overview

App. Date	Description of Innovation	Benefit	Source
1842	First recorded installation of nonreinforced concrete pipe in Mohawk, New York.	First record of concrete pipe installation in the US.	ACPA, 1981
1896	First concrete production in the United States using slag cement, a supplementary cementitious material (SCM).	SCM provides higher concrete strengths, reduced permeability, sulfate attack, improved sustainability, improved finishability, etc. allowing for a higher quality product for the end user.	SCA, 2020
Early 1900's	Slag cement began being utilized more commonly.	Cementing material used to increase durability and strength.	Kosmatka et al., 2002
1906	First recorded use of dry cast concrete to create a reinforced concrete pipe in the U.S.	Built a framework for automated dry cast equipment which allow for quick production rate.	*Washabaugh, 2020
1930's	Modern admixture technology started with basic air-entraining agents, retarders, accelerators, and water reducers in North America.	Admixtures provided a paradigm shift in the concrete production industry by allowing a wider range of capabilities in a variety of production environments and constraints while providing higher quality finished products.	Harris & Jeknavorian, 2014
1930's	Air-entraining admixtures developed.	Improve workability and durability in freeze-thaw climates.	Kosmatka et al., 2002
1930's	Fly ash, a powder resembling cement, began being used in concrete as a supplementary cementitious material (SCM).	Improved sustainability by decreasing the carbon footprint of cement and promoted reuse of coal by-products that would otherwise end up in a landfill. Improved long-term strength of end product.	Kosmatka et al., 2002
1932	Water reducers first developed.	Reduce water content to a minimum 5%.	Roberts, 2018
1950's	Concrete admixtures began seeing widespread usage in concrete.	Benefits of using admixtures were spread to more regions allowing for overall improvement of concrete products nation-wide.	Harris & Jeknavorian, 2014
1962	ASTM first published its C494 standard, now titled "Historical Standard: Standard Specification for Chemical Admixtures for Concrete," which set performance criteria for five types of admixtures: A, B, C, D and E.	Standards of admixtures allowed for an improved consistency of quality concrete mixes and heightened understanding of effects and benefits of individual admixtures throughout the industry.	Harris & Jeknavorian, 2014
1975	Superplasticizers or "high-range water reducers" were developed.	Increase flowability and reduce water-cement ratio (minimum 12%).	Levy, 2012
1979	The first corrosion-inhibiting admixture was introduced to help mitigate the impact of chloride salt (NaCl) attack on steel reinforcement.	Improved long-term durability and service life of concrete infrastructure products, especially in the coastal regions and colder climate regions that utilize salt for ice melt.	Harris & Jeknavorian, 2014
1980	Types F and G, high-range water-reducing admixtures, were added to the C494 standard.	Improved durability of low water to cementitious ratio concrete as well as workability which then indirectly improves safety and production rate.	Harris & Jeknavorian, 2014
1980's	Hydration control admixtures developed.	Control setting.	Kosmatka et al., 2002
1981	ACI Committee 212 publishes the "Report on Chemical Admixtures for Concrete" which did not include high range water reducers.	Standards of admixtures allowed for an improved consistency of quality concrete mixes and heightened understanding of effects and benefits of individual admixtures throughout the industry.	Khan, 2018
1983	The U.S. EPA issued "Cement and Concrete Containing Fly Ash: Guidelines for Federal Procurement".	Encouraged the use of concrete containing fly ash in federally funded projects which improved sustainability, workability, and strength of concrete.	EPA, 1983
1984	Mid-range water reducers were first introduced.	Provided significant water reduction (between 6 and 12%) and allowed for reduced stickiness, improved finish ability,	Kosmatka et al., 2002

		pump ability, and place ability of concrete containing Supplementary.	
1986	Self-Consolidating Concrete (SCC) was first developed by Prof. Okamura at Ouchi University, Japan.	Allows for labor, time, and cost savings as well as increased job site safety and for better working conditions. It also results in high-quality, smooth concrete surfaces.	Lemay, 2019
Mid 1990's	Polycarboxylates (i) in HRWR admixtures were introduced in North America. This was the first introduction of SCC to North America.	Improved flexibility, enhanced workability, workability retention with minimal set retardation, and very good finishing characteristics.	Harris & Jeknavorian, 2014
1996	Shrinkage-reducing admixtures were introduced.	Helped to address cracking issues associated with autogenous drying in high-performance concrete.	Harris & Jeknavorian, 2014

REINFORCEMENT

Concrete has many properties that prove its value as a building material. Some of the most advantageous properties of concrete are its compression strength, durability, fire resistance, versatility, and low cost. However, one disadvantage of concrete is its low tensile strength. In the mid-1800's, it was discovered that by embedding steel into concrete the resulting composite material allows for higher tensile strength while still maintaining all of the beneficial concrete properties. This composite material, reinforced concrete, was patented in 1867 (Moussard et al, 1970).

Nearly 30 years later, reinforced concrete pipe (RCP) was first developed and utilized by France in 1896 (ACPA, 1981). This innovative method for adding strength to concrete pipe caught on, and eventually made its way to America in 1905. By 1906, many concrete pipes over 24 inches in diameter, as well as some as small as 18 inches, were made with reinforcement. Over the next several decades, continued advancement in research and technology led to better understanding of RCP. This allowed the industry to develop standards for manufacturing and gradually advance the use of reinforcement by optimizing the amount and placement of steel which allowed for improved structural designs and efficient material usage. Additionally, production efficiencies have advanced which have improved manufacturing speed, safety, and accuracy.

REINFORCEMENT OPTIMIZATIONS IN CONCRETE PIPE AND BOX STANDARDS

Through the years, due to research and improvements in technology, concrete pipe standards (C14, C76, C506, C507, and C1417) and box culvert standards (C789, C850, C1433, and C1577) have undergone revisions. Some of these revisions have increased the quality and performance of the reinforcement while also optimizing steel areas, allowing reduced material cost. Described below are several changes that have allowed for reduced steel areas, which results in reduced cost to the manufacturer and end user.

Concrete Pipe Reinforcement Optimizations

Testing done in 1967 by the Ohio Concrete Pipe Manufacturers Association, in conjunction with the Ohio State Highway Department, included a "quadrant" reinforcement design. Excellent results from this study led to added provisions to C76 in 1970 (Zicaro & Hodge, n.d.). Zicaro and Hodge noted, "These changes provided for positioning and proportioning of reinforcement on a "quadrant design" basis, as well as the position and proportion of reinforcement using an inner circular cage in conjunction with an elliptical cage. By using these alternate reinforcement designs, it may be possible to reduce the amount of reinforcement by as much as 43% by weight." (p. 4)

In the 1970's and 80's the American Concrete Pipe Association instituted a long-range research program. This research touched upon a variety of the aspects dealing with the design of concrete pipe. Better quantitative methods for predicting the earth loads and pressure distributions on buried pipe were established and utilized in the finite element program SPIDA (Soil Pipe Interaction Design and Analysis). The results of this were the Standard Installations, a set of four quantifiable pipe installations that can be easily understood by both engineers and contractors. More rational strength and serviceability design methods were incorporated into the design of concrete pipe as well. Designing for the installed condition became much more accurate, and even three-edge bearing designs were optimized with a reduction of the outer steel cage ratio to the inner steel cage ratio from 0.75 to 0.60 in 1985.

In 2011 the behavior of cold drawn steel was evaluated on the National Cooperative Highway Research Program (NCHRP) Report 679 and a research proposal by the University of Nebraska at Lincoln stated that a power formula instead of a classical elastic-plastic stress strain curve, can be used for cold drawn wire for precast RCP (Shahrooz et al., 2011; Hanna & Tadros, n.d.). This has not been applied to American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) design yet, but it does offer a realistic approach to the flexural design for RCP.

Concrete Box Section Reinforcement Optimizations

In 2007, research on fatigue evaluation for reinforced concrete box sections showed that the maximum stress levels for wire reinforcement given in the AASHTO LRFD Design Fatigue provisions were extremely conservative when applied to precast box sections (Maximos et al., 2007). Another research project on "Experimental and Finite Element Based Investigation of Shear Behavior in Reinforced Concrete Box Culverts" allowed for reduction of excessive longitudinal reinforcement in the top of top slabs (elimination of As6 reinforcement), and this update was put into place in the ASTM Standards, C1433 and C1577.

REINFORCEMENT TECHNOLOGY AND PRODUCTION ADVANCEMENTS

Advancements in technology and production of steel reinforcement have led to immense improvement in the rate of production and efficiency of material use in both concrete pipe and monolithic concrete boxes. For pipe production, the development of an automated cage machine in the 1960's allowed for automated production of reinforcing cages, which saved time (BFT International, 2011). Also, traditional box sections started with individually tied rebar as its main reinforcement. This method of reinforcing was time-consuming. Soon, welded wire reinforcement (WWR) began being utilized as an alternative to rebar in reinforced concrete box (RCB) section production. These standard sheets consisted of two cold formed steel wires fused together in opposite directions. As processes advanced, automated production of two different wire sizes in one direction welded to one wire size in the opposite direction in precise spacing and various lengths led to the development of "AccuCage". AccuCage, which combines the words 'accurate' and 'cage', was one of the biggest reinforcement innovations in box section manufacturing as it eliminated the practice of "over-steeling" - placement of more steel than required in certain areas. This advancement allowed for the use of exact, or near exact, areas of steel as required by the structural design (*Nobles, 2020). Advancements in reinforcement production have allowed for many improvements within the concrete pipe industry. Automation in reinforcement cage manufacturing has allowed for safer, faster, and more precise production which benefits both the manufacturer and the end user of precast pipe and box section products. Furthermore, the ability to develop cages with precise areas of steel has allowed for less material waste, creating a more cost friendly and sustainable end product.

Many innovations have occurred which have improved the efficiency of reinforcement utilization in concrete pipe and monolithic concrete boxes. Research and the development of standards have led to a greater understanding of the installation tensile forces that occur within our products, which has allowed the industry to optimize the use of reinforcement and provide a consistent level of quality. New production methods and technologies have allowed for optimization of steel placement, precise areas of reinforcement, faster, and safer manufacturing techniques. This has enabled the industry to increase efficiency in production, optimize material use, and develop a safer manufacturing process while reducing the end-product cost to the user.

Table 4 below provides a general overview of key advancements in the precast concrete industry regarding reinforcement.

Table 4: Reinforcement Innovations Overview

App. Date	Description of Innovation	Benefit	Source
1867	Joseph Monier was the first person to patent reinforced concrete.	The composite material improved tensile properties of concrete.	Moussard et al, 1970
1896	France first began utilizing reinforcement in concrete pipes.	Allowed for increased strength and service life of concrete pipe.	ACPA, 1981
1905	Reinforced concrete pipes were introduced to America. By 1906, many concrete pipes over 24 inches in diameter, as well as some as small as 18 inches were made with reinforcement.	Allowed for increased strength and service life of concrete pipe.	ACPA, 1981
1930	ASTM C75 Standard Specification for Reinforced Concrete Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1930	ASTM C76 Standard Specification for Reinforced Concrete Culvert and Storm Drain Pipe.	Improved manufacturing standards and consistency which allowed for consistent quality end product. Since C76 was developed, it has been updated over time to improve reinforcement requirements and other improvements for the benefit of the end user.	ASTM C76 note
1936	ASTM A185 Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete.	Initial standard for WWR allowed for widespread use by concrete manufacturers.	*Pelter, 2020

Early 1940's	Welded wire reinforcement began being used as concrete pipe reinforcement.	Improved reinforcement options for concrete pipe allowed for shorter production time and easier manufacturing.	*Pelter, 2020
Late 1950's	American Iron and Steel Institute sponsored a testing program under the direction of Frank J. Heger at Massachusetts Institute of Technology. Heger and associates prepared two reports, *Structural behavior of Circular Concrete Pipe Reinforced with Welded Wire Fabric* and *The Structural Behavior of Circular Reinforced Concrete Pipe – Development of Theory*.	Research on reinforcement allowed for better understanding of stresses in pipe caused by applied loads which could allow for reduction of steel area to reduce material cost and provide better production efficiency.	ACPA, 1981; Heger et al., 1963
1957	ASTM C75 and C76 were combined into one standard, C76 Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1960's	Semi-automated and automated RCP cage making machines came into operation in Europe.	Allowed for quicker, safer cage production by reducing required manual labor.	*D'Angelo, 2020
Early 1960's	First cage machines were manually operated and produced straight cage only. These machines were slow by today's standard.	Built initial framework for automated cage production processes.	Black Clawson, n.d.
Early 1960's	Minimum yield strength for plain wire increased to 65 ksi.	Improved strength of steel allowed for lesser steel area in pipe and optimal use of materials.	*Pelter, 2020
1963	Need for automation of cage machines was recognized and double wrap versions of automated cage production was developed.	Significantly increased production capabilities of cage machines.	Black Clawson, n.d.
1964	ASTM A497 Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete	Allowed for improved bond between concrete and reinforcement.	*Pelter, 2020
1967	Research on a "quadrant" reinforcement design was conducted.	Allowed for reduction in the amount of reinforcement by as much as 43% by weight.	Zicaro & Hodge, n.d.
1967	The necessity of adjusting each individual drive plate was eliminated through the development of a cage machine which incorporated a synchronized wire feed system.	Allowed for the automatic production of consistently straight cages with improved speed and ease of production.	Black Clawson, n.d.
1969	First automatic bell end cage machine was developed.	Allowed for improved reinforcement areas in the bell end of pipe increasing overall product durability.	Black Clawson, n.d.
Early 1970's	Convoluted wire began to be used for concrete pipe reinforcement.	Simplified the reinforcement at the bell end of a pipe. The convoluted wires were expanded so they can conform to the contour/shape of the bell end.	*Pelter, 2020
1970	Quadrant reinforcement design was added to C76.	Allowed for standard utilization of quadrant reinforcement for all manufactures.	Zicaro & Hodge, n.d.
1970's	Bending equipment for welded wire reinforcement began to be developed and manufactured (some producers had homemade bending equipment before this time).	Improved speed and safety of production.	*Pelter, 2020
1974	ASTM C789 Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers.	These shapes are ideal in situations where there is limited cover over the top of the pipe, while increasing the hydraulic capacity of the system.	ASTM
1976	ASTM C850 Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft of Cover Subjected to Highway Loadings.	These shapes are ideal in situations where there is limited cover over the top of the pipe, while increasing the hydraulic capacity of the system.	ASTM
Early 1980's	Automated mesh rolling machines were first introduced. Later versions were developed.	Improved speed and safety of production.	*D'Angelo, 2020
1980's	Automated cage making machines began being used in the United States.	Allowed for quicker, safer cage production.	Marshall, 2020
1984	Research was published that analyzed thrust forces on buried concrete pipe using SPIDA (Soil Pipe Interaction Design Analysis).	Four standard installations were developed as a result of the research.	Heger, 1984
1985	Reduction of outer steel cage to inner steel cage ratio revised from 0.75 to 0.60.	Reduction of raw materials while maintaining the same strength and serviceability which improved product sustainability.	Heger, 1985

1990's	New versions of automated mesh rolling machine were developed.	Improved speed and safety of production.	*D'Angelo, 2020
1990's	Maximum yield strength for wire increased to 80 ksi.	Improved strength of steel allowed for lesser steel area in pipe and optimal use of materials.	*Pelter, 2020
1990's	Production of welders to produce exact steel areas required.	Allowed for sustainable, optimal, and efficient use of materials.	*Pelter, 2020
2000's	AccuCage or "Varicage" which involved WWR sheets with two different line wires and a single cross wire was developed.	Allowed for more accurate areas of steel for more optimal material use and reduced material costs.	*Nobles, 2020
Early 2000's	Production of quick changeover welders for mesh reinforcement that allowed for changeovers in less than an hour.	Allowed mesh manufacturers to produce smaller orders of sheets more efficiently by reducing the time it takes to changeover mesh size and style which ultimately saved time and money for the end user.	*Pelter, 2020
2007	Research on fatigue of wire reinforcement used in precast box culverts resulted in an exclusion of the AASHTO LRFD Design fatigue provisions.	Prevented increased steel use in box section manufacturing saving on material cost.	Maximos et al., 2007
2008	Research conducted on "Experimental and Finite Element Based Investigation of Shear Behavior in Reinforced Concrete Box Culverts".	Allowed for elimination of As6 reinforcement all together and this update was put into place in the ASTM standards C1433 and C1577.	Abolmaali et al., 2008
2010	Production of welders to produce circular sheets.	Improved capabilities of reinforcement production.	*Pelter, 2020
2011	Behavior of cold drawn steel was evaluated by the University of Nebraska at Lincoln and their research proposal stated that a power formula instead of elastic-plastic stress strain curve, can be used for cold drawn wire for precast reinforced concrete pipe.	Offered a realistic approach to the flexural design for RCP.	Shahrooz et al., 2011; Hanna & Tadros, n.d.

JOINTS

Concrete pipe and monolithic concrete box joints have experienced many improvements over the last fifty years but more so in the last thirty years. As technology and infrastructure needs are changing through time, the performance of precast concrete pipe and its joints has been optimized to not only satisfy these needs but to ensure ease of installation and safety. Precast concrete pipe offers durability, strength, and joint system performance with a variety of shapes. In addition to the inherent strength of precast concrete pipe and boxes, the joint can be designed to meet different sealing requirements, with the ability to accommodate lateral or longitudinal movement by using several joint options including mortar, flexible joint sealants, rubber gaskets, and external sealing bands.

VARIETY OF JOINT ADVANCEMENTS

A variety of joint advancements have allowed for a wide range of product features and enhanced performance characteristics for all types and shapes of concrete pipe. A few of the most significant joint options that have been developed over time are described below.

Flexible Sealant Joints

Specification ASTM C990 defines the required composition and performance testing requirements for preformed butyl sealants. Sealants that meet this standard will provide a reasonable level of assurance for performance in soil tight requirements.

O-Ring Rubber Gasket Joints

The O-ring rubber gasket joints were first patented in the United States in 1939 with expanded use starting in 1945. Various O-ring joint configurations were developed over the following years which are still in use today. The O-ring rubber gasket joints provide optimal sealing of the pipe connection allowing for extended pressure resistance as compared to other joint options.

Offset Joint

The offset step joint was introduced in 1972, which provided an alternate joint and rubber gasket design. This joint improved ease of manufacturing and gave rise to a variety of different gasket profile shapes, each offering unique benefits.

Pre-Lubricated Gasket

The pre-lubricated gasket was first introduced in 1989. This gasket does not require lubrication nor equalization during installation. All of these attributes potentially allow for an easier, quicker, and more error-free installation which ultimately results in time and money savings to the product end user.

Rubber Gasket Joints for Shaped Concrete Pipe and Monolithic Concrete Boxes

Leak resistant, rubber gasket joints for shape concrete pipe and monolithic concrete boxes were developed in the late twentieth century and early twenty first century. Gasketed joints became available for box sections in 1995, for elliptical pipe in 2000 and for arch pipe in 2004, which resulted in improved, leak resistant joints.

There have been considerable developments and improvements to precast concrete joints over the years with the most significant advancements in the last 30 years. Evolution of joint configurations has allowed for more joint options and new gasket designs. Furthermore, advancements in the industry have had an incredible improvement on quality control which has benefited both the installer and end user by providing improved pipe and box connections. Advancements in concrete joint designs provide enhanced performance characteristics with respect to resistance to infiltration of groundwater and backfill material, resistance to exfiltration of sewage or stormwater, ability to accommodate lateral or longitudinal movement, continuity and smooth flow line and ease of installation, all of which provide ample benefits to the end users of these products.

Table 5 provides a list of notable innovations that have occurred throughout history regarding concrete pipe joints.

Table 5: Joints Innovations Overview

App. Date	Description of Innovation	Benefit	Source
Early 1950's	Jointing of concrete pipe evolved from the basic mortar joint to flexible joints using rubber gaskets of various designs.	Rubber gaskets resulted in silt tight and leak resistant joints as well as more homed and more durable joints.	ACPA, 1981
1959	ASTM C443 Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets was approved.	This Standard resulted in quality control parameters of rubber gasketed joints.	ASTM
1972	Offset step joint introduced.	Improved production – easier to produce and introduced larger, profile gaskets.	*Sharma, 2019
1989	Pre-Lubricated gasket introduced in Canada in 1989.	This invention resulted in easier to install and more error free joints.	*Sharma, 2019
1991	ASTM C990 Standard Specification for Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1993	Pre-lubricated gasket introduced in U.S.	Allowed for easier to install and more error free joints to be used in the US.	*Sharma, 2019
1995	Box section rubber gasket joints introduced.	New box production equipment that provided rounded corners on the joints allowed for production of gasketed box sections.	*Sharma, 2019
2000	Elliptical pipe rubber gasket joints introduced.	Provided more versatility in design with silt tight and leak resistant joints.	*Sharma, 2019
2004	Arch pipe rubber gasket joints introduced.	Provided more versatility in design with silt tight and leak resistant joints.	*Sharma, 2019
2005	ASTM C1619 Standard Specification for Elastomeric Seals for Joining Concrete Structures was originally approved.	This standard was the result of removing the rubber gasket portion of C443 (Joints) from that Standard and creating a separate Standard for the rubber gaskets.	ASTM C13
2005	External joint hydrostatic test developed.	Allowed for an alternate method of hydrostatic testing, which better replicates field conditions since it is an infiltration test. This was especially a factor for hydrostatic testing of gasketed box sections.	*Sharma, 2019
2006	ASTM C1628 Standard Specification for Joints for Concrete Gravity Flow Sewer Pipe, Using Rubber Gaskets.	This Standard covers the design of joints and the requirements for rubber gaskets for flexible, leak resistant joints where measurable or defined infiltration or exfiltration is a factor of the design.	ASTM
2008	Latest equipment advancement in tools for joint measuring.	New and more accurate methods for measuring equipment and finished product for better quality control.	*Sharma, 2019

PRODUCTION & QUALITY

Concrete pipe production is a series of harmonically tuned procedures starting from raw materials storage and ending with a product loaded on a truck ready to be transferred to the installation site. Quality is a major part of each production stage and is the tool that assures that products meet the end user requirements. In the early 1900's, the demand for precast pipe was mainly for rural land drainage applications. In recent years the demand and applications of precast products has increased tremendously, and the precast concrete pipe industry has been keeping up with this increased demand through innovative production methods that allow for more versatile product shapes and sizes, improved production speed through automation and improved quality.

ADVANCEMENTS IN PRODUCT SHAPE AND SIZE

Since the introduction of concrete pipe, its typical attributes have been expanded upon to help achieve added functionality. An example of this is the introduction of the reinforced concrete elliptical pipe in 1952 (*Washabaugh, 2020). Specifications for these products were approved by the ASTM C13 Committee on Concrete Pipes in 1963. These shapes are ideal in situations where there is limited cover over the top of the pipe, while increasing the hydraulic capacity of the system. Box sections were first built in 1964 and standardized via ASTM C789 and C850 in 1974 and 1976, respectively. Both standards were combined into C1433 in 1999. Further advancements have resulted in automated production methods for all pipe sizes, as well as larger diameter pipes and joints that offer a large variety of applications.

PLANT AUTOMATION

Pipe production by using machinery was first introduced in the United States in 1916, when the first tamp machines were developed (ACPA, 1981). Prior to this all concrete pipe produced was hand-made. Two new production methods were introduced to the industry in 1918 and 1922, the double tamp machines and centrifugal method, respectively (ACPA, 1981). As the demand for concrete pipe increased, Jessen of Salt Lake City, Utah developed the Cen Vi-Ro process in 1950 which uses a combination of centrifugal, vibration and roller processes (ACPA, 1981). In this process, the form is spun by rubber truck tires with arrangements such that the form can be also vibrated. In the early 1970's precast box production methods and machines were introduced (ACPA 1981). Automation in precast plants has continued to evolve which has allowed the industry to respond to the increased demand, while at the same time, increasing the quality, speed, and safety of production. Automation in the plant can be introduced by automating individual stages of production or by complete plant automation.

Automation of Individual Stages

In existing plants, automation can be applied in every production stage, from automatic cage machines, robots assembling cages and forms, equipment that can place and strip the entire assembly in chambers where they are cured, hydrostatic testing, and pipe marking, and machines that handle and move the pipe to the yard.

Complete Plant Automation

For fully automated plants, plant automation allows production to run 24/7 and offers a cleaner, safer, and healthier workplace for its employees. Another aspect of this is the ability to monitor production operations and troubleshoot via satellite cameras. Both dry cast and packerhead are manufacturing techniques for producing precast concrete pipe that are most frequently associated with today's most advanced production plants. Forms are removed from the pipe, as soon as the pipe is produced. They are then available for re-use several times during the day. In recent years, automation is focused on wet cast machines used in the precast plants as well as adjusting production to new materials like SCC.

QUALITY CONTROL

In an effort to improve the overall quality of all concrete pipe products throughout the nation, American Concrete Pipe Associations' (ACPA) Quality Committee developed the QCast program from 1992 through 1997. The first version of the standard was published in 1998 and included Guidelines on Sanitary Sewer Pipe and Storm Sewer and Culvert Pipe. Auditor selection, training, and the first plant audits were performed in December of 1998. Unannounced audits for re-certification began in 2002. The committee continued its efforts to expand the standard and in 2003 requirements for box sections were added to the program. In 2012 the QCast program was extended to international audits as well which is a practice followed today. Tests and product requirements are periodically updated through input from ACPA's Quality and Safety Committees to conform to the most current practices. The QCast manual is updated at least annually and it is effective on January 1st of each year. Another program developed by ACPA's Quality Committee is Quality School which was first launched in 2006 and gives quality control personnel background information and training to perform their duties with an understanding of their responsibilities.

As described above, the advancements in quality and production have largely been due to the addition of new product shapes and expanded sizes, automation of the equipment used in production, and the addition of quality control processes at each production stage. Other improvements, such as increased mix design capabilities, higher concrete strength, improved machine production and increased knowledge and use of admixtures, have helped improve production and quality control, as well. Additionally, research is conducted, and time is invested when considering changes that aim to have a positive impact on the end user by improving the quality of the products. Through ACPA's cross training programs, the precast industry's workforce has become more technically knowledgeable, more talented, and has increased the ability of the plant to function as a well-coordinated team.

Table 6 provides a list of notable innovations that have occurred throughout history regarding concrete pipe production and quality.

Table 6: Production and Quality Innovations Overview

App. Date	Description of Innovation	Benefit	Source
1900	First tamp machines were developed. All concrete pipe produced prior was hand-made.	First form of automated pipe production which provides safer and faster pipe production.	ACPA, 1981
1906	First recorded use of dry cast concrete to create a reinforced concrete pipe in the U.S.	Built a framework for automated dry cast equipment which allow for quick production rate.	*Washabaugh, 2020
1916	First packerhead machine introduced in the U.S.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	*Washabaugh, 2020
1918	Double tamp machines were introduced making it possible to tamp on both sides of the reinforcement.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1920	Centrifugal method of making concrete pipe was introduced from Australia.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1922	New method of centrifugal production was utilized in eastern U.S.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1925	Annual production of concrete pipe reached one million tons per year.	Signifies improved production capabilities to supply national demand.	ACPA, 1981
1930	Annual production of concrete pipe reached two million tons per year.	Advancements in manufacturing allowed concrete pipe manufacturers to keep up with demand.	ACPA, 1981
1945	Johnson of California, using Johnson-Prosser patents, centrifuged concrete pipe, spinning the form on the bottom, inside a drum spinner. This system was used in Texas and California.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1947	First roller suspensions process was used in U.S.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1950	Annual production of concrete pipe reached four million tons per year.	Signifies improved production capabilities to supply national demand.	ACPA, 1981
1950	Jessen of Salt Lake City, Utah developed the Cen Vi-Ro process which uses a combination of centrifugal, vibration and roller processes. In this process, the form is spun by rubber truck tires with arrangements so that the form can be also vibrated.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1952	Precast elliptical pipe was invented by Edward P. Washabaugh.	These shapes are ideal in situations where there is limited cover over the top of the pipe.	*Washabaugh, 2020
1960's	Equipment to produce and handle pipe in longer lengths, up to sixteen feet, was introduced.	Allowed for larger product size.	ACPA, 1981
1960's	Development of first semi-automated RCP reinforcement cage machine by MBK.	Allowed for quicker, safer cage production.	BFT International, 2011
1963	ASTM C506 Standard Specification for Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe.	These shapes are ideal in situations where there is limited cover over the top of the pipe, while increasing the hydraulic capacity of the system.	ASTM
1963	ASTM C507 Standard Specification for Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe.	These shapes are ideal in situations where there is limited cover over the top of the pipe, while increasing the hydraulic capacity of the system.	ASTM
1964	Precast concrete box sections were developed at Northern Concrete Pipe in Michigan to provide an alternative to cast-in-place structures.	Allowed for quicker construction of box culvert projects saving time and money.	*Washabaugh, 2020

1970	Annual production of concrete pipe reached more than ten million tons per year.	Signifies improved production capabilities to supply national demand.	ACPA, 1981
1970's	In-plant air test was developed and is still in use. Some manufacturers use a stamp or other symbol to mark pipe which have passed the test.	Improved quality control.	ACPA, 1981
1974	ASTM C789 Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers.	These shapes are ideal in situations where there is limited cover over the top of the pipe, while increasing the hydraulic capacity of the system.	ASTM
1976	ASTM C850 Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft. of Cover Subjected to Highway Loadings.	These shapes are ideal in situations where there is limited cover over the top of the pipe, while increasing the hydraulic capacity of the system.	ASTM
1978	Annual production of concrete pipe amounted to nearly 13 million tons.	Signifies improved production capabilities to supply national demand.	ACPA, 1981
1992 – 1997	Guidelines of Q-Cast Program were developed.	Provided national guidelines which ensured quality of concrete pipe, box sections, and other concrete structures.	ACPA
1998	First plant inspected utilizing Q-Cast Program.	Continually improve the overall quality of all concrete pipe products.	ACPA Manufacturing Committee minutes
1999	ASTM C789 and ASTM C850 combined under ASTM C1433 Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers.	Allowed manufactures and specifiers to use one specification for box culvert regardless of the fill height.	ASTM
2005	ASTM developed standard C1577 on concrete box sections according to AASHTO LRFD.	Broadened the range of standard designs for box sections related to various design and loading requirements.	ASTM
2006	ACPA started providing Safety Awards to promote safe manufacturing practices.	Recognizes innovations in safety and shares these innovations throughout the industry.	ACPA
2006	Quality School or Quality Aspects in Production CPU.	More technically knowledgeable through ACPA's training, with employees becoming more talented via cross training and ability to function in different positions.	ACPA manufacturing committee minutes
2015	Quality Chairman Awards.	Recognizes innovations in quality and shares these innovations throughout the industry.	ACPA
2019	QCast gets ANSI accreditation.	Provides confidence and trust to interested parties that the QCast program operates in a competent, consistent, and impartial manner.	ACPA
2020	Gasket Manufacturing part of QCast program.	Central Gasket Facility Certification.	ACPA

STANDARDS & DESIGN AIDS

The concrete pipe manufacturing industry has experienced continuous improvements over time. Many of these improvements are a direct result of standards and design aids that have been developed and utilized nationally. The extensive advancements and use of standards and design aids allows for a consensus of acceptance requirements between producers and users of the products. These tools have allowed the end user to benefit from consistency in material use, production efficiency, and product quality. Eliminating variability in product design and production allows for united advancements in the industry.

DEVELOPMENT OF STANDARDS

One of the first committees that focused on the development and advancement of concrete pipe standards was the ASTM committee C13 on Concrete Pipe which was formed in 1930. Since then, C13 has expanded to a diverse membership of over 225 technical experts from 11 different countries and manages more than 65 standards related to sewers, culverts, irrigation and drainage systems, low pressure pipeline systems, and for factory-made compression and self-energizing joints. The membership of this committee works continuously to ensure the development of quality and proven standards that will best serve the needs of the product users. To date, a variety of standards have been established through professional involvement in organizations such as ASTM, Canadian Standards Association (CSA), American Society of Civil Engineers (ASCE), and AASHTO. These standards provide guidance on design, manufacturing, installation, testing, economic evaluation, performance, and post installation of concrete pipe and monolithic concrete boxes.

DESIGN TOOLS & PROGRAMS

Additionally, as design and manufacturing standards have become more prevalent over time, design tools and programs have been developed to assist manufacturers that produce concrete pipe as well as engineers that design or specify them. Design tools and programs allow engineers and manufacturers to develop comprehensive designs for even the most complex projects with consistency, ease, and time efficiency. Several precast concrete pipe software design programs have been developed and improved over the years. SPIDA, a finite element analysis program, developed in the late 1970's and 1980's from empirical research sponsored by the ACPA, resulted in a better understanding of loads on an installed concrete pipe. PIPECAR (Pipe Culvert Analysis and Reinforcement) and BOXCAR (Box Culvert Analysis Reinforcing) were both submitted to the Federal Highway Administration (FHWA) in 1982. They enabled quick and efficient designs to be done properly by designers with varying experience levels.

Another design software developed for the concrete pipe industry was Pipe Pac software developed in 1996. This design software can be used to conduct Three-Edge-Bearing design, CAPE (Cost Analysis of Pipe Envelope), and LCA (Life Cycle Analysis). Eriksson Culvert (2010), originally called ET Culvert, was developed for box culvert design and load rating to replace BOXCAR which was no longer maintained by the ACPA or FHWA. Eriksson Pipe (2018) was developed as an update to the PIPECAR software for RCP design. Additionally, there have been many other design and manufacturing resources developed over the years such as Fill Height Tables, Hydraulic Design, Cost Comparison and others which have enabled heightened efficiency in concrete pipe development and advancement.

Produced and updated by some of the most experienced industry members along with other professionals in the trade, concrete pipe and box standards, and design aids allow for high-quality and consistently designed products across the board. Updates of these tools have been developed to accommodate design improvements and technological advancements. Standards and design aids provide end users with assurance that their products are designed and produced in a timely manner and at a consistent quality. Additional developments regarding concrete pipe standards and design aids are shown in table 7 below.

Table 7: Standards and Design Aids Innovations Overview

App. Date	Description of Innovation	Benefit	Source
1917	ASTM C14 Standard Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1930	ASTM C75 Standard Specification for Reinforced Concrete Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1930	ASTM C76 Standard Specification for Reinforced Concrete Culvert and Storm Drain Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1930	ASTM Committee C13, Concrete Pipe was formed.	ASTM Standards ensure quality control measures for the benefit of the public.	ASTM
1955	ASTM C361 Standard Specification for Reinforced Concrete Low-Head Pressure Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1957	ASTM C75 and C76 were combined into one standard, C76 Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1963	ASTM C506 Standard Specification for Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1963	ASTM C507 Standard Specification for Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1970	ASTM C655 Standard Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe	New national standard allowed for improved and consistent quality products across the board.	ASTM
1970's and 1980's	Soil-Pipe Interaction Design and Analysis (SPIDA), a finite-element computer program, was developed.	A research tool providing for more advanced design practice for pipe-soil installations.	Heger, 1984
1974	ASTM C789 Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers.	New national standard allowed for improved and consistent quality products across the board.	ASTM

1975	ASTM C822 Standard Terminology Relating to Concrete Pipe and Related Products.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1976	ASTM C850 Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft of Cover Subjected to Highway Loadings.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1977	ASTM C877 Standard Specification for External Sealing Band for Concrete Pipe, Manholes, and Precast Box Sections.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1979	ASTM C923 Standard Specification for Resilient Connectors Between Reinforced Concrete Manhole Structures, Pipes, and Laterals.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1982	PIPECAR software pipe design program introduced.	Provided tool for expedited pipe designs and options.	ACPA
1982	BOXCAR software box sections design program introduced.	Provided tool for expedited box sections designs and options.	ACPA
1982	ASTM C969 Standard Practice for Infiltration and Exfiltration Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1983	ASTM C 985 Standard Specification for Nonreinforced Concrete Specified Strength Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1989	ASTM C1103 Standard Practice for Joint Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1991	ASTM C990 Standard Specification for Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1996	PipePac software introduced.	Provided tool for Three-Edge-Bearing design, installation cost comparisons, and Life Cycle Analysis.	ACPA
1998	ASTM C1417 Standard Specification for Manufacture of Reinforced Concrete Sewer, Storm Drain, and Culvert Pipe for Direct Design.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1999	ASTM C1433 Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2000	Round Pipe Fill Height Tables Developed.	Great tool for checking for pipe class with different installation types.	ACPA
2000	ASTM C1479 Standard Practice for Installation of Precast Concrete Sewer, Storm Drain, and Culvert Pipe Using ASTM Standard Installations.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2005	ASTM C1577 Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD.	Broadened the range of standard designs for box sections related to various design and loading requirements.	ASTM
2005	ASTM Standard C1619 - Standard Specification for Elastomeric Seals for Joining Concrete Structures was originally approved.	This standard was the result of removing the rubber gasket portion of C443 (Joints) from that Standard and creating a separate Standard for the rubber gaskets.	ASTM
2006	ASTM C1628 Standard Specification for Joints for Concrete Gravity Flow Sewer Pipe, Using Rubber Gaskets.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2009	Round Pipe Fill Height Tables meeting LRFD developed.	Provided tool for checking pipe class with different installation types per LRFD.	ACPA
2009	Arch and Elliptical Pipe Fill Height Tables meeting LRFD developed.	Provided tool for checking pipe class with different installation types per LRFD.	ACPA
2009	ASTM C1677 Standard Specification for Joints for Concrete Box, Using Rubber Gaskets.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2010	Eriksson Culvert software for box sections design introduced.	Provided a new tool for box sections design which included AASHTO LRFD.	ACPA

2011	ASTM C1675 Standard Practice for Installation of Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2014	ASTM C1786 Standard Specification for Segmental Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2013	ASTM C1765 Standard Specification for Steel Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2013	Compare Flow application developed.	Application for comparison of flow capacity for different pipe size for specified flow and roughness coefficient.	ACPA
2015	ASTM C1818 Standard Specification for Synthetic Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2017	ASTM C1846 Standard Specification for Performance Based Manufacture of Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2017	ASTM C1837 Standard Specification for Production of Dry Cast Concrete Used for Manufacturing Pipe, Box, and Precast Structures.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2017	ASTM C1840 Standard Practice for Inspection and Acceptance of Installed Reinforced Concrete Culvert, Storm Drain, and Storm Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2018	Eriksson Pipe software for pipe design developed.	Provided a new tool for pipe design which included AASHTO LRFD.	ACPA
2019	ASTM C1894 Standard Guide for Microbially Induced Corrosion of Concrete Products.	New national standard allowed for improved and consistent quality products across the board.	ASTM

INSTALLATION

Advancements in the concrete pipe industry have been widespread, ranging from innovations of the individual materials used to make the products to optimizations of product design to the development of new production technologies and standards to ensure timely manufacturing with quality control. These advancements have been complimented by advancements in the installation of concrete pipe and monolithic concrete boxes. Research and the development of standard installation requirements and procedures have allowed for consistent and proven product installation nationally. Also, innovative installation techniques such as trenchless and flooded backfill installations have allowed for safer, quicker, and more disruption-free concrete pipe installations for even the most complex projects.

INSTALLATION RESEARCH AND STANDARDS DEVELOPMENT

In the late 1970's and 1980's, ACPA instituted a long-range research program with the overall objective of evaluating the performance of concrete pipe-soil installations and soil-structure interaction analysis for more accurate and effective designs. In the past, designers of buried pipe had specified embedment details based on beddings developed by Marston and Spangler in the 1920's and 1930's. Advancements in computer science allowed for a finite element analysis of the structural behavior of buried pipe in its installed condition through a program called SPIDA, which resulted in new Standard Installations and a direct design procedure (SIDD - Standard Installations Direct Design) that were incorporated into ASCE Standard 15 in 1993 and again incorporated into ASTM specifications in 2000 through the development of C1479. These Standard Installations offer versatile, conservative, and quantifiable installation direction for the designer and the contractor. Within the last ten years, new standards to aid installation of other precast concrete products such as box sections have been developed. The growth of the precast concrete box sections product line prompted the need for an ASTM standard guidelines for box section installation. In 2011 the new ASTM Standard C1675, Standard Practice for Installation of Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers was approved. Additionally, specifications with criteria for evaluating pre-installed and installed precast concrete products have been developed. AASHTO R73, Standard Practice for Evaluation of Precast Concrete Drainage Products evaluates the product pre-installed and ASTM C1840, Standard for Inspection and Acceptance of Installed Reinforced Concrete Culvert, Storm Drain, and Storm Sewer Pipe evaluates the product in the installed condition.

Trenchless Installation

Trenchless installations such as jacking and microtunneling have been used in the United States for over 70 years (Sterling, 2018). While these processes are not new, they are becoming more common due to the many benefits they offer. Trenchless installations are less invasive than traditional trenched installations and they can require little to no confined space entry which allows for increased job site safety. Furthermore, they can provide other benefits such as less environmental impact, reduced construction time and the ability to complete complex pipeline projects that span under a dense development or waterway. Concrete pipe is an exceptional product to utilize in trenchless installation due to its high compressive strength, durability, and versatility. The high compressive strength and durability enables long drives with larger jacking forces as opposed to other materials. Also, the joints of concrete pipe can be custom designed to suit a variety of trenchless installation equipment.

Flooded Backfill

The Iowa Department of Transportation developed a method of consolidating soils around a concrete pipe during installation using flooded backfill. Evaluated during the 2005 construction season in Iowa, flooded backfill is a new and innovative method of installing concrete pipe and box culverts that allows lower cost and higher quality installations as opposed to standard methods (Musgrove, 2020). Due to the benefits of flooded backfill, this procedure has been incorporated into the Iowa DOT Specification under Section 2402 (Musgrove, 2020; Iowa DOT, 2020). The flooded backfill process requires the contractor to place soil plugs at both ends of the pipe and then apply 2-foot lifts of uncompacted floodable backfill (permeable soils, granular with less than 4% passing #200 sieve). In between each lift, compaction is achieved by flooding the surface of the backfill with water for approximately 3 minutes with a minimum of 2-inch diameter hose. Once flooding is complete, a proof test is conducted with a vibratory compactor to ensure proper compaction before proceeding with the next lift (Musgrove, 2020). Research and installation data from Iowa DOT have proven that necessary compaction requirements can be achieved with the flooded backfill procedure. This simple process results in more simplified, consistent, and high-quality pipe installations. Additionally, since minimal compaction equipment and trench entry is required, it also allows for safer and quicker installation resulting in higher cost savings to the product end user. Concrete pipe producers are pursuing continued research to determine the necessary criteria for expanded use of this method in other regions of the country.

As advancement continues to occur throughout the entire concrete pipe industry, innovations in installation have not been left out. The ACPA research on the structural behavior of buried pipe in its installed condition was a major breakthrough in the science of pipe-soil installations. These Standard Installations are:

Versatile: One can choose between installation types and pipe strengths (classes) to suit specific site conditions to optimize the total installed cost.

Conservative: Analyses are based on the worst case (embankment) loadings, voids in the haunch zone, and measurable requirements that more accurately assess long-term performance.

Quantifiable: Definite and measurable levels of acceptance are prescribed, which provide better direction for the designer and the contractor.

This research and resulting standards were then followed by standards for precast box sections. Furthermore, innovative techniques of concrete pipe installations such as trenchless and flooded backfill have provided many benefits including, but not limited to, cost and time savings, improved safety, and the ability to perform complex projects with ease.

Table 8 provides a list of notable innovations that have occurred throughout history regarding the installation of concrete pipe.

Table 8: Installation Innovations Overview

App. Date	Description of Innovation	Benefit	Source
1896	First identified use of pipe jacking to install concrete pipe under Northern Pacific Railroad.	Advancement in pipe installation which allows for pipe installation without a trench and with little to no disruption to developments above the pipeline.	Sterling, 2018
1950's	Pipe jacking became a more popular alternative installation method.	Improved technology and methodology allowed for more pipe to be installed trenchless.	Sterling, 2018

1984	First microtunneling project occurred in the United States.	This method of installation allowed for complete tunneling control from ground level requiring no person entry into the tunnel.	Sterling, 2018
1993	New Standard Installations from extensive research and the use of SPIDA incorporated in ASCE Standard 15, Standard Practice for Direct Design of Buried Concrete Pipe in Standard Installations (SIDD).	In the late 1970's and 1980's, ACPA instituted a long-range research program with the overall objective of evaluating the performance of concrete pipe-soil installations and improving design practice for pipe-soil installations.	ACPA
1995	First recorded trenchless installation with the use of pilot tube guidance in the United States.	Allows for trenchless installations to stay on the path of alignment with more precision.	Sterling, 2018
1996	The Standard Installations were incorporated into AASHTO.	This built the framework for DOTs to begin incorporating the Standard Installations into their standard drawings.	AASHTO
2000	ASTM C1479 Standard Practice for Installation of Precast Concrete Sewer, Storm Drain, and Culvert Pipe Using ASTM Standard Installations.	Provided an installation guide for precast concrete pipe with four types (each) of trench and embankment installations.	ASTM
2005	Development of Flooded Backfill Procedure Specified in Iowa DOT.	Provides a new, innovative, less costly and high-quality method for pipe installation.	Musgrove, 2020
2010	The first curved microtunneling project in the U.S. was constructed.	Allows for trenchless installation for complex projects requiring curved alignments.	Sterling, 2018
2011	ASTM C1675 Standard Practice for Installation of Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers.	The growth of the precast concrete box sections product line prompted the need for standard installation practice guidelines for box sections.	ASTM
2016	AASHTO R73, Standard Practice for Evaluation of Precast Concrete Drainage Products.	Provides guide for finished but not installed concrete pipe	AASHTO
2017	ASTM C1840 Standard Practice for Inspection and Acceptance of Installed Reinforced Concrete Culvert, Storm Drain, and Storm Sewer Pipe.	The expansion of post installation inspections, especially via video cameras, resulted in the need for requirements and guidelines for inspection and acceptance of installed reinforced concrete pipe.	ASTM

RESEARCH

Research is the driving force of innovation. All innovations described throughout this report were made possible by the extensive efforts that concrete pipe producers have poured into research and development throughout the history of precast concrete pipe and monolithic concrete boxes. These research efforts have resulted in micro-innovations that may not have made the front page of Engineering New-Record (ENR) magazine, but have slowly and consistently advanced precast products throughout time. From steel design to mix design to joint design, all of these features - while not necessarily "new" by nature - have been optimized over decades and will continue to be optimized into the next generation of our infrastructure.

A COLLECTION OF INDIVIDUALLY INNOVATIVE MANUFACTURERS

One understated advantage of the concrete pipe industry is that it is made up of hundreds of different producers in various environments with different backgrounds and areas of expertise. Each company is incentivized to innovate as the market drives each individual producer towards their own path of optimization. The innovations that prove to be effective over time are soon adopted by other producers, and the cycle continues, driving increased product performance and manufacturing efficiencies for end-users. This has given the industry a very diverse platform from which many innovations have been, and continue to be, produced.

ONGOING INVESTIGATIONS OF POTENTIAL FUTURE INNOVATIONS

But besides the routine improvements concrete manufacturers adopt on a regular basis, concrete pipe producers are also constantly looking for the next big thing. To help further the progress of the industry as a whole, the ACPA formed a specific Research and Education Committee in 2008 to lead and encourage collaboration efforts between RCP manufacturers to promote innovative advancements. Many people pose the question, "Where is the concrete pipe industry headed next? What's the next big innovation?" To answer these question, we need look no further than at a few of many ongoing research projects being undertaken by producers and the ACPA Research & Education committee that are seeking to improve the quality and efficiency of the RCP of the future.

Fiber-reinforced Concrete Pipe

The first such example of this is fiber-reinforced concrete pipe. While synthetic, steel, and glass reinforcement fibers have been used in the manufacture of concrete since the 1960's, it was only in the last decade that they gained widespread popularity. Currently, the RCP industry is looking at ways to further improve the durability of products using fiber additives. The use of fibers in concrete pipe may have the potential to increase overall compressive strength, freeze-thaw durability, and abrasion resistance. With a potential increase in strength, thinner walls may be permissible with fiber-reinforced concrete. This could lead to a lighter-weight RCP and RCB product, making handling and mobilization more economical and sustainable. However, research is still underway on this subject and the potential benefits and downfalls of fiber-reinforced concrete pipe is still unknown.

Mitigating Microbial Induced Corrosion

Another great example of ongoing improvements is the current research to address microbially induced corrosion (MIC) concerns for concrete pipe and manholes used in sanitary sewer applications. In situations where sewage flows are turbulent and substantial sewer (H2S) gases are present, concrete pipes can be subject to chemical degradation and corrosion. For years there had been methods and additives available to help mitigate these concerns, but there had been little work completed to determine the relative effectiveness of each potential solution. Completed and on-going research seeks to standardize the evaluation process for effective MIC mitigation. This will result in improved performance and life-expectancy for concrete products in sanitary environments and more dependable solutions for MIC mitigation.

While innovation is the fuel for progress and societal advancement, research is the fuel for innovation. The research and development that has been completed within the RCP and RCB industry is substantial and has resulted in many innovative optimizations throughout the course of history. As research continues to remain a high priority for ACPA, and hundreds of individual concrete pipe and box section manufacturers continue to do their own product research and development, many new and innovative product advancements will inevitably arise. These future innovations will continue to serve the needs of an ever-changing society for generations to come.

CONCLUSION

As discussed through the entirety of this document, concrete pipe has had an extensive history with many advancements that have shaped the concrete pipe product line which includes box sections, elliptical and arch pipe. Innovations have occurred through all aspects of the industry spanning from the concrete used to produce the products, the embedded reinforcement, the actual product design, the production processes and standards used to ensure quality and the installation of the products itself. Most, if not all, of these industry advancements have been a direct result of the extensive amounts of research conducted by ACPA and other organizations such as ASTM, ACI, and ASCE, national and international universities and the hundreds of individual pipe manufactures. The common denominator of all advancements, has always been to benefit growing communities by offering a durable and sustainable product.

One unique quality of the concrete pipe industry is that it is made up of hundreds of individual concrete pipe manufactures that are all governed, in most part, by the same set of national standards. The competitive nature of the individual producers that are spread throughout the whole nation encourages each manufacture to find 'the next best thing' in order to grow their business and gain a larger market share. Due to the magnitude of individual innovation efforts, explorations of methods to improve capabilities to meet industry demands is constantly underway. At the same time, all manufactures are governed by the same product standards which only change to allow for heavily researched and proven advancements which will provide benefits to the industry and product users. Recall Figure 1 in the Introduction of this document. The organization in which the concrete pipe industry is set up allows for only the most responsible and ethical innovations to become incorporated into standards. This eliminates most, if not all, risks to the product end users.

While innovation acts as a fuel for societal advancements, it is critical that infrastructure innovations remain at the highest standards of evaluation before being implemented. Infrastructure is the foundation of our society in that it impacts each and every industry in our nation. Infrastructure materials implemented nationally without proper research and diligent investigations can have disastrous impacts to every aspect of our society. Innovations to our nation's infrastructure should only be implemented with the utmost care and responsibility. The concrete pipe industry has organized itself in a way that will ensure that proper investigations and research is completed on all new innovations before allowing them to become standard.

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APPENDIX A – OVERALL INDUSTRY INNOVATIONS LISTED SEQUENTIALLY

Table 9: Overall Concrete Pipe Innovations Overview

App. Date	Description of Innovation	Benefit	Source
1842	First recorded installation of concrete pipe in Mohawk, New York.	First record of concrete pipe installation in the U.S.	ACPA, 1981
1867	Joseph Monier was the first person to patent reinforced concrete.	The composite material improved tensile properties of concrete.	Moussard et al, 1970
1896	First concrete production in the United States using slag cement, a supplementary cementitious material (SCM).	SCM provides higher concrete strengths, reduced permeability, sulfate attack, improved sustainability, improved finishability, etc. allowing for a higher quality product for the end user.	SCA, 2020
1896	First identified use of pipe jacking to install concrete pipe under Northern Pacific Railroad.	Advancement in pipe installation which allows for pipe installation without a trench and with little to no disruption to developments above the pipeline.	Sterling, 2018
1896	France first began utilizing reinforcement in concrete pipes.	Allowed for increased strength and service life of concrete pipe.	ACPA, 1981
Early 1900's	Slag cement began being utilized more commonly.	Cementing material used to increase durability and strength.	Kosmatka et al., 2002
1900	First tamp machines were developed. All concrete pipe produced prior was hand-made.	First form of automated pipe production which provides safer and faster pipe production.	ACPA, 1981
1905	Reinforced concrete pipes were introduced to America. By 1906, many concrete pipes over 24 inches in diameter, as well as some as small as 18 inches were made with reinforcement.	Allowed for increased strength and service life of concrete pipe.	ACPA, 1981
1906	First recorded use of dry cast concrete to create a reinforced concrete pipe in the U.S.	Built a framework for automated dry cast equipment which allow for quick production rate.	*Washabaugh, 2020
1916	First packerhead machine introduced in the U.S.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	*Washabaugh, 2020
1917	ASTM C14 Standard Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1918	Double tamp machines were introduced making it possible to tamp on both sides of the reinforcement.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1920	Centrifugal method of making concrete pipe was introduced from Australia.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1922	New method of centrifugal production was utilized in eastern U.S.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1925	Annual production of concrete pipe reached one million tons per year.	Signifies improved production capabilities to supply national demand.	ACPA, 1981
1930	Annual production of concrete pipe reached two million tons per year.	Advancements in manufacturing allowed concrete pipe manufacturers to keep up with demand.	ACPA, 1981
1930	ASTM C75 Standard Specification for Reinforced Concrete Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1930	ASTM C76 Standard Specification for Reinforced Concrete Culvert and Storm Drain Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1930	ASTM Committee C13, Concrete Pipe was formed.	ASTM Standards ensure quality control measures for the benefit of the public.	ASTM
1930's	Air-entraining admixtures developed.	Improve workability and durability in freeze-thaw climates.	Kosmatka et al., 2002
1930's	Fly ash, a powder resembling cement, began being used in concrete as a supplementary cementitious material (SCM).	Improved sustainability by decreasing the carbon footprint of cement and promoted reuse of coal by-products that would otherwise end up in a landfill. Improved long-term strength of end product.	Kosmatka et al., 2002
1930's	Modern admixture technology started with basic air-entraining agents, retarders, accelerators, and water reducers in North America.	Admixtures provided a paradigm shift in the concrete production industry by allowing a wider range of	Harris & Jeknavorian, 2014

		capabilities in a variety of production environments and constraints while providing higher quality finished products.	
1932	Water reducers first developed.	Reduce water content to a minimum 5%.	Roberts, 2018
1936	ASTM A185 Standard Specification for Steel Welded Wire Reinforcement, Plain, for Concrete.	Initial standard for WWR allowed for widespread use by concrete manufacturers.	*Pelter, 2020
Early 1940's	Welded wire reinforcement being used as concrete pipe reinforcement.	Improved reinforcement options for concrete pipe allowed for shorter production time and easier manufacturing.	*Pelter, 2020
1945	Johnson of California, using Johnson-Prosser patents, centrifuged concrete pipe, spinning the form on the bottom, inside a drum spinner. This system was used in Texas and California.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1947	First roller suspensions process was used in U.S.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
Early 1950's	Jointing of concrete pipe evolved from the basic mortar joint to flexible joints using rubber gaskets of various designs.	Rubber gaskets resulted in silt tight and leak resistant joints as well as more homed and more durable joints.	ACPA, 1981
1950	Annual production of concrete pipe reached four million tons per year.	Signifies improved production capabilities to supply national demand.	ACPA, 1981
1950	Jessen of Salt Lake City, Utah developed the Cen Vi-Ro process which uses a combination of centrifugal, vibration and roller processes. In this process, the form is spun by rubber truck tires with arrangements so that the form can be also vibrated.	Provided broader selection of automated pipe manufacturing, improving production speed and safety.	ACPA, 1981
1950's	Concrete admixtures began seeing widespread usage in concrete.	Benefits of using admixtures were spread to more regions allowing for overall improvement of concrete products nation-wide.	Harris & Jeknavorian, 2014
1950's	Pipe jacking became a more popular alternative installation method.	Improved technology and methodology allowed for more pipe to be installed trenchless.	Sterling, 2018
1952	Elliptical pipes were invented by Edward P. Washabaugh.	These shapes are ideal in situations where there is limited cover over the top of the pipe.	*Washabaugh, 2020
1955	ASTM C361 Standard Specification for Reinforced Concrete Low-Head Pressure Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1957	ASTM C75 and C76 were combined into one standard, C76 Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
Late 1950's	American Iron and Steel Institute sponsored a testing program under the direction of Frank J. Heger at Massachusetts Institute of Technology. Heger and associates prepared two reports, *Structural behavior of Circular Concrete Pipe Reinforced with Welded Wire Fabric* and *The Structural Behavior of Circular Reinforced Concrete Pipe – Development of Theory*.	Research on reinforcement allowed for better understanding of stresses in pipe caused by applied loads which could allow for reduction of steel area to reduce material cost and provide better production efficiency.	ACPA, 1981; Heger et al., 1963
1959	ASTM C443 Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets was approved.	This Standard resulted in quality control parameters of rubber gasketed joints.	ASTM
Early 1960's	First cage machines were manually operated and produced straight cage only. These machines were slow by today's standard.	Built initial framework for automated cage production processes.	Black Clawson, n.d.
Early 1960's	Minimum yield strength for plain wire increased to 65 ksi.	Improved strength of steel allowed for lesser steel area in pipe and optimal use of materials.	*Pelter, 2020
1960's	Semi-automated and automated RCP cage making machines came into operation in Europe.	Allowed for quicker, safer cage production by reducing required manual labor.	*D'Angelo, 2020
1960's	Development of first semi-automated RCP reinforcement cage machine by MBK.	Allowed for quicker, safer cage production.	BFT International, 2011
1960's	Equipment to produce and handle pipe in longer lengths, up to sixteen feet, was introduced.	Allowed for larger product size.	ACPA, 1981

1962	ASTM first published its C494 standard, now titled "Historical Standard: Standard Specification for Chemical Admixtures for Concrete," which set performance criteria for five types of admixtures: A, B, C, D and E.	Standards of admixtures allowed for an improved consistency of quality concrete mixes and heightened understanding of effects and benefits of individual admixtures throughout the industry.	Harris & Jeknavorian, 2014
1963	ASTM C506 Standard Specification for Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1963	ASTM C507 Standard Specification for Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1963	Need for automation of cage machines was recognized and double wrap versions of automated cage production was developed.	Significantly increased production capabilities of cage machines.	Black Clawson, n.d.
1964	ASTM A497 Standard Specification for Steel Welded Wire Reinforcement, Deformed, for Concrete.	Allowed for improved bond between concrete and reinforcement.	*Pelter, 2020
1964	Precast concrete box sections were developed at Northern Concrete Pipe in Michigan to provide an alternative to cast-in-place structures.	Allowed for quicker construction of box culvert projects saving time and money.	*Washabaugh, 2020
1967	Research on a "quadrant" reinforcement design was conducted.	Allowed for reduction in the amount of reinforcement by as much as 43% by weight.	Zicaro & Hodge, n.d.
1967	The necessity of adjusting each individual drive plate was eliminated through the development of a cage machine which incorporated a synchronized wire feed system.	Allowed for the automatic production of consistently straight cages with improved speed and ease of production.	Black Clawson, n.d.
1969	First automatic bell end cage machine was developed.	Allowed for improved reinforcement areas in the bell end of pipe increasing overall product durability.	Black Clawson, n.d.
Early 1970's	Convoluted wire began to be used for concrete pipe reinforcement.	Simplifies the reinforcement at the bell end of a pipe. The convoluted wires are expanded so they can conform to the contour/shape of the bell end.	*Pelter, 2020
1970	Annual production of concrete pipe reached more than ten million tons per year.	Signifies improved production capabilities to supply national demand.	ACPA, 1981
1970	ASTM C655 Standard Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1970	Quadrant reinforcement design was added to C76.	Allowed for standard utilization of quadrant reinforcement for all manufactures.	Zicaro & Hodge, n.d.
1970's	Bending equipment for welded wire reinforcement is being manufactured (some producers had homemade bending equipment before this time).	Improved speed and safety of production.	*Pelter, 2020
1970's	In-plant air test was developed and is still in use. Some manufacturers use a stamp or other symbol to mark pipe which have passed the test.	Improved quality control.	ACPA, 1981
1970's and 1980's	Soil-Pipe Interaction Design and Analysis (SPIDA), a finite-element computer program, was developed.	Evolved the understanding and designing buried concrete pipe installations.	Heger, 1984
1972	Offset step joint introduced.	Improved production – easier to produce and introduced larger, profile gaskets.	*Sharma, 2019
1974	ASTM C789 Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1975	ASTM C822 Standard Terminology Relating to Concrete Pipe and Related Products.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1975	Superplasticizers or "high-range water reducers" were developed.	Increase flowability and reduce water-cement ratio (minimum 12%).	Levy, 2012
1976	ASTM C850 Standard Specification for Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft of Cover Subjected to Highway Loadings.	New national standard allowed for improved and consistent quality products across the board.	ASTM

1977	ASTM C877 Standard Specification for External Sealing Band for Concrete Pipe, Manholes, and Precast Box Sections.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1978	Annual production of concrete pipe amounted to nearly 13 million tons.	Signifies improved production capabilities to supply national demand.	ACPA, 1981
1979	ASTM C923 Standard Specification for Resilient Connectors Between Reinforced Concrete, Manhole Structures, Pipes, and Laterals.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1979	The first corrosion-inhibiting admixture was introduced to help mitigate the impact of chloride salt (NaCl) attack on steel reinforcement.	Improved long-term durability and service life of concrete infrastructure products, especially in the coastal regions and colder climate regions that utilize salt for ice melt.	Harris & Jeknavorian, 2014
Early 1980's	Automated mesh rolling machines were first introduced. Later versions were developed.	Improved speed and safety of production.	*D'Angelo, 2020
1980	Types F and G, high-range water-reducing admixtures, were added to the C494 standard.	Improved durability of low water to cementitious ratio concrete as well as workability which then indirectly improves safety and production rate.	Harris & Jeknavorian, 2014
1980's	Automated cage making machines began being used in the United States.	Allowed for quicker, safer cage production.	Marshall, 2020
1980's	Hydration control admixtures developed.	Control setting.	Kosmatka et al., 2002
1981	ACI Committee 212 publishes the "Report on Chemical Admixtures for Concrete" which did not include high range water reducers.	Standards of admixtures allowed for an improved consistency of quality concrete mixes and heightened understanding of effects and benefits of individual admixtures throughout the industry.	Khan, 2018
1982	ASTM C969 Standard Practice for Infiltration and Exfiltration Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1982	BOXCAR software box sections design program introduced.	Provided tool for expedited box sections designs and options.	ACPA
1982	PIPECAR software pipe design program introduced.	Provided tool for expedited pipe designs and options.	ACPA
1983	ASTM C 985 Standard Specification for Nonreinforced Concrete Specified Strength Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1983	The U.S. EPA issued "Cement and Concrete Containing Fly Ash: Guidelines for Federal Procurement".	Encouraged the use of concrete containing fly ash in federally funded projects which improved sustainability, workability, and strength of concrete.	EPA, 1983
1984	First microtunneling project occurred in the United States.	This method of installation allowed for complete tunneling control from ground level requiring no person entry into the tunnel.	Sterling, 2018
1984	Mid-range water reducers were first introduced.	Provided significant water reduction (between 6 and 12%) and allowed for reduced stickiness, improved finish ability, pump ability, and place ability of concrete containing Supplementary.	Kosmatka et al., 2002
1984	Research was published that analyzed thrust forces on buried concrete pipe using SPIDA (Soil Pipe Interaction Design Analysis).	Four standard installations were developed as a result of the research.	Heger, 1984
1985	Reduction of outer steel cage to inner steel cage ratio revised from 0.75 to 0.60.	Reduction of raw materials while maintaining the same strength and serviceability which improved product sustainability.	Heger, 1985
1986	Self-Consolidating Concrete (SCC) was first developed by Prof. Okamura at Ouchi University, Japan.	Allows for labor, time, and cost savings as well as increased job site safety and for better working conditions. It also results in high-quality, smooth concrete surfaces.	Lemay, 2019
1989	ASTM C1103 Standard Practice for Joint Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1989	Pre-Lubricated gasket introduced in Canada in 1989.	This invention resulted in easier to install and more error free joints.	*Sharma, 2019
1990's	Maximum yield strength for wire increased to 80 ksi.	Improved strength of steel allowed for lesser steel area in pipe and optimal use of materials.	*Pelter, 2020

1990's	New versions of automated mesh rolling machine were developed.	Improved speed and safety of production.	*D'Angelo, 2020
1990's	Production of welders to produce exact steel areas required.	Allowed for sustainable, optimal, and efficient use of materials.	*Pelter, 2020
1991	ASTM C990 Standard Specification for Joints for Concrete Pipe, Manholes, and Precast Box Sections Using Preformed Flexible Joint Sealants.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1992 – 1997	Guidelines of Q-Cast Program were developed.	Provided national guidelines which ensured quality of concrete pipe, box sections, and other concrete structures.	ACPA
1993	New Standard Installations from extensive research and the use of SPIDA incorporated in ASCE Standard 15, Standard Practice for Direct Design of Buried Concrete Pipe in Standard Installations (SIDD).	In the late 1970's and 1980's, ACPA instituted a long-range research program with the overall objective of evaluating the performance of concrete pipe-soil installations and improving design practice for pipe-soil installations.	ACPA
1993	Pre-Lubricated gasket introduced in U.S.	Allowed for easier to install and more error free joints to be used in the US.	*Sharma, 2019
Mid 1990's	Polycarboxylates (i) in HRWR admixtures were introduced in North America. This was the first introduction of SCC to North America.	Improved flexibility, enhanced workability, workability retention with minimal set retardation, and very good finishing characteristics.	Harris & Jeknavorian, 2014
1995	First recorded trenchless installation with the use of pilot tube guidance in the United States.	Allows for trenchless installations to stay on the path of alignment with more precision.	Sterling, 2018
1995	Box section rubber gasket joints introduced.	New box production equipment that provided rounded corners on the joints allowed for production of gasketed box sections.	*Sharma, 2019
1996	PipePac software introduced.	Provided tool for Three-Edge-Bearing, design, installation cost comparisons, and Life Cycle Analysis.	ACPA
1996	Shrinkage-reducing admixtures were introduced.	Helped to address cracking issues associated with autogenous drying in high-performance concrete.	Harris & Jeknavorian, 2014
1996	The Standard Installations were incorporated into AASHTO.	This built the framework for DOTs to begin incorporating the Standard Installations into their standard drawings.	AASHTO
1998	ASTM C1417 Standard Specification for Manufacture of Reinforced Concrete Sewer, Storm Drain, and Culvert Pipe for Direct Design.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1998	First plant inspected utilizing Q-Cast Program.	Continually improve the overall quality of all concrete pipe products.	ACPA Manufacturing Committee minutes
1999	ASTM C1433 Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers.	New national standard allowed for improved and consistent quality products across the board.	ASTM
1999	ASTM C789 and ASTM C850 combined under ASTM C1433 Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers.	Allowed manufactures and specifiers to use one specification for box culvert regardless of the fill height.	ASTM
Early 2000's	Production of quick changeover welders for mesh reinforcement that allowed for changeovers in less than an hour.	Allowed mesh manufacturers to produce smaller orders of sheets more efficiently by reducing the time it takes to changeover mesh size and style which ultimately saved time and money for the end user.	*Pelter, 2020
2000	ASTM C1479 Standard Practice for Installation of Precast Concrete Sewer, Storm Drain, and Culvert Pipe Using ASTM Standard Installations.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2000	Elliptical pipe rubber gaskets introduced.	Provided more versatility in design with silt tight and leak resistant joints.	*Sharma, 2019
2000	Round Pipe Fill Height Tables Developed.	Great tool for checking for pipe class with different installation types.	ACPA
2000's	AccuCage or "Varicage" which involved WWR sheets with two different line wires and a single cross wire was developed.	Allowed for more accurate areas of steel for more optimal material use and reduced material costs.	*Nobles, 2020

2004	Arch pipe rubber gaskets introduced.	Provided more versatility in design with silt tight and leak resistant joints.	*Sharma, 2019
2005	ASTM C1577 Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD.	Broadened the range of standard designs for box sections related to various design and loading requirements.	ASTM
2005	ASTM C1619 Standard Specification for Elastomeric Seals for Joining Concrete Structures was originally approved.	This standard was the result of removing the rubber gasket portion of C443 (Joints) from that Standard and creating a separate Standard for the rubber gaskets.	ASTM
2005	ASTM developed standard C1577 on concrete box sections according to AASHTO LRFD.	Broadened the range of standard designs for box sections related to various design and loading requirements.	ASTM
2005	Development of Flooded Backfill Procedure Specified in Iowa DOT.	Provides a new, innovative, less costly and high-quality method for pipe installation.	Musgrove, 2020
2005	External joint hydrostatic test developed.	Allowed for an alternate method of hydrostatic testing, which better replicates field conditions since it is an infiltration test. This was especially a factor for hydrostatic testing of gasketed box sections.	*Sharma, 2019
2006	ACPA started providing Safety Awards to promote safe manufacturing practices.	Recognizes innovations in safety and shares these innovations throughout the industry.	ACPA
2006	ASTM C1628 Standard Specification for Joints for Concrete Gravity Flow Sewer Pipe, Using Rubber Gaskets.	This Standard covers the design of joints and the requirements for rubber gaskets for flexible, leak resistant joints where measurable or defined infiltration or exfiltration is a factor of the design.	ASTM
2006	ASTM C1628 Standard Specification for Joints for Concrete Gravity Flow Sewer Pipe, Using Rubber Gaskets.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2006	Quality School or Quality Aspects in Production CPU.	More technically knowledgeable through ACPA's training, with employees becoming more talented via cross training and ability to function in different positions.	ACPA manufacturing committee minutes
2007	Research on fatigue of wire reinforcement used in precast box culverts resulted in an exclusion of the AASHTO LRFD Design fatigue provisions.	Prevented increased steel use in box section manufacturing saving on material cost.	Maximos et al., 2007
2008	Latest equipment advancement in tools for joint measuring.	New and more accurate methods for measuring equipment and finished product for better quality control.	*Sharma, 2019
2008	Research conducted on "Experimental and Finite Element Based Investigation of Shear Behavior in Reinforced Concrete Box Culverts".	Allowed for elimination of As6 reinforcement all together and this update was put into place in the ASTM standards C1433 and C1577.	Abolmaali et al., 2008
2009	Arch and Elliptical Pipe Fill Height Tables meeting LRFD developed.	Provided tool for checking pipe class with different installation types per LRFD.	ACPA
2009	ASTM C1677 Standard Specification for Joints for Concrete Box, Using Rubber Gaskets.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2009	Round Pipe Fill Height Tables meeting LRFD developed.	Provided tool for checking pipe class with different installation types per LRFD.	ACPA
2010	Eriksson Culvert software for box sections design introduced.	Provided a new tool for box sections design which included AASHTO LRFD.	ACPA
2010	Production of welders to produce circular sheets.	Improved capabilities of reinforcement production.	*Pelter, 2020
2010	The first curved microtunneling project in the U.S. was constructed.	Allows for trenchless installation for complex projects requiring curved alignments.	Sterling, 2018
2011	ASTM C1675 Standard Practice for Installation of Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2011	Behavior of cold drawn steel was evaluated by the University of Nebraska at Lincoln and their research proposal stated that a power formula instead of elastic-plastic stress strain curve, can be used for cold drawn wire for precast reinforced concrete pipe.	Offered a realistic approach to the flexural design for RCP.	Shahrooz et al., 2011; Hanna & Tadros, n.d.
2013	Compare Flow application developed.	Application for comparison of flow capacity for different pipe size for specified flow and roughness coefficient.	ACPA

2014	ASTM C1786 Standard Specification for Segmental Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2015	ASTM C1818 Standard Specification for Synthetic Fiber Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2015	Quality Chairman Awards.	Recognizes innovations in quality and shares these innovations throughout the industry.	ACPA
2016	AASHTO R73, Standard Practice for Evaluation of Precast Concrete Drainage Products.	Provides guide for finished but not installed concrete pipe.	AASHTO
2017	ASTM C1837 Standard Specification for Production of Dry Cast Concrete Used for Manufacturing Pipe, Box, and Precast Structures.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2017	ASTM C1840 Standard Practice for Inspection and Acceptance of Installed Reinforced Concrete Culvert, Storm Drain, and Storm Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2017	ASTM C1846 Standard Specification for Performance Based Manufacture of Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2018	Eriksson Pipe software for pipe design developed.	Provided a new tool for pipe design which included AASHTO LRFD.	ACPA
2019	ASTM C1894 Standard Guide for Microbially Induced Corrosion of Concrete Products.	New national standard allowed for improved and consistent quality products across the board.	ASTM
2019	QCast gets ANSI accreditation.	Provides confidence and trust to interested parties that the QCast program operates in a competent, consistent, and impartial manner.	ACPA
2020	Gasket Manufacturing part of QCast program.	Central Gasket Facility Certification.	ACPA