NATIONAL CORRUGATED STEEL PIPE ASSOCIATION **ISSUED: June 1999**

Competitive*products*

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Reinforced Concrete Pipe

I. Promoting Against Concrete Pipe

RCP is perceived by many engineers and specifiers as being a better product than CSP. This is an opinion that must be offset with facts about the two products. CSP has a number of advantages over RCP and these need to be highlighted. The facts are that if an agency is willing to spend the same amount of money on CSP products that they spend on RCP, they will at a minimum have equal and competing products to chose from. In most circumstances, CSP can be shown to provide a better value than RCP if all aspects of an application are considered. The following are the CSP advantages that should be promoted.

A. Durability of CSP

With the proper selection of coating and steel thickness, CSP can meet any service life or environmental condition specified for RCP. If galvanized does not meet the necessary requirements, several special coatings are available on CSP products, such as aluminized Type-2, asphalt coated and paved, polymerized asphalt and polymer-precoat. These coatings give CSP a durability equal to that of RCP, and are most likely available at a cost less than that of RCP. This is the most important consideration in the comparison of RCP and CSP. Coatings are critical to the use of CSP in drainage applications. A strong case must be made for the durability of CSP coatings. **Make use of the CSP Durability Guide!**

B. CSP More Structurally Efficient

Because of the soil-structure interaction nature of CSP installation, CSP is far superior to RCP in structural efficiency. In many cases, such as under deeper fills, RCP will contain more steel than CSP, but the placement of the steel in RCP means it is not used efficiently. The support provided by the soil around the CSP pipe, enhances the efficiency of CSP as a structural member.

C. Questions About RCP Design

The only aspect of RCP installation that has an impact on structural design is the quality of the bedding. The new SIDD design method reduces the quality of the bedding, anticipates lateral support from the backfill similar to that of a flexible pipe, and is still able to reduce the pipe strength. Is RCP a rigid or flexible pipe? Is the bedding important to pipe performance? Point Out the Confusion and Uncertainty Regarding RCP Design Methods!

D. Easier Design of CSP

The typical CSP structural design involves the use of one height-of-cover table. Every RCP design is special and more complex than CSP design. Tables and graphs make RCP design somewhat easier, but a number of variables, such as bedding class, trench width and soil type must be considered. The tables provide earth loads for cover of 2 to 50 feet, highway loads for cover of 0.5 to 9 feet and railroad loads for covers of 1 to 30 feet. For any application with cover greater than 50 feet, no design aids are available. Tables and graphs do not exist for the SIDD design method. For deep cover and installations using the SIDD method, the designer must devote considerable effort to the design.

E. CSP Quality is Visible

CSP does not need to be tested to verify manufactured quality. Gages for measuring the thickness of the steel and the coating thickness make verification of CSP quality an easy matter. The quality of RCP is not as easily verified.

- Certifications are provided for the raw materials: cement, aggregates and any admixtures used in the concrete mix.
- Certifications are provided for the reinforcing steel material in the pipe.
- Compression tests are performed on the concrete used to make the RCP.

These material certifications do not provide all the information needed about the RCP product. RCP is a composite made of steel and concrete. If the steel is not properly placed, the RCP will not achieve its design strength. The only way to verify steel placement is to destroy the pipe to measure concrete cover or to test load the pipe. **CSP Quality is Visible; RCP Quality is Not.**

F. Better Fabrication Quality with CSP

Fabrication of CSP does not adversely affect the pipe's structural integrity since the weld used in fabrication generally equals or exceeds the area of steel cut away. Fabrication of RCP products is performed in such a way as to raise questions about structural integrity. The RCP fabrication process includes removal of concrete with hammers, cutting reinforcing with torches or saws, repositioning the pieces, welding the reinforcing in the new configuration and packing the open space with concrete by hand. The resulting product looks bad and has questionable quality.

G. Positive Connection for CSP Joints

CSP joints must comply with the mechanical requirements of ASTM A798. This standard provides minimum values for joint performance including shear, moment, and pull-apart capacity. RCP does not have such requirements. RCP joints possess minimal resistance to pull-apart forces, with any such resistance resulting from friction created by the sealant. Any moment capacity that exists at RCP joints also comes from sealant friction. CSP joints have a mechanical connection created by the external bands, which enhance shear, moment and pull-apart capacity. RCP should not be used for sloped pipe because of the lack of a mechanical joint connection.

H. Greater Lateral Resistance at CSP Joints

Joints are the weak link in the RCP pipe system. In order to create the tongue & groove (or bell & spigot) configuration and an annular space for the joint sealant, the cross-section of the ends of RCP are reduced by more than 50%. This results in a severely diminished capability to withstand lateral movement and loads such as those resulting from differential settlement.

I. Fewer Joints with CSP

The most typical length of RCP is 8 feet, versus the typical 20-foot length for CSP. This means 2.5 times as many joints to install and that many more opportunities for problems such as differential settlement, joint opening on slopes and frost induced movement. These problems will cause increased joint leakage and increase the Mannings "n" value for the line.

J. Deflection of RCP Joints

To avoid having to fabricate elbows, RCP manufacturers will promote the incorporation of large radii into sewer lines. This enables them to deflect pipe joints (increase the joint gap on one side) in lieu of fabricating elbows. This results in increased joint leakage, further reduces the resistance to differential movement and increases the likelihood of point loadings on parts of the joint.

K. Tightness of CSP Joints is Adequate

The suppliers of RCP will promote the watertight joints they claim RCP offers. In most cases, even for storm sewers, extremely tight joints are not required. The EPA allows a certain amount of leakage on sanitary sewer lines, therefore it is unreasonable to require even tighter joints on storm sewers. Most RCP joint specifications have an allowable leakage rate for pipe that is tested in the plant. After installation, RCP joints will usually leak as a result of breakage or cracks in the joint parts.

L. Lighter Weight of CSP Means Lower Cost

The lighter weight of CSP greatly reduces the costs associated with transporting and installing CSP. The weight of RCP means most shipments are limited by weight, not the space available. Because of the heavier weight, RCP is usually delivered close to the point of installation, whereas CSP may be stockpiled in some out-of the-way location on the site and moved as needed. Comparable weights of CSP and RCP are as follows:

	Weight (lbs. per foot)	
Pipe Size	**CSP**	**RCP**
12"	10	93
48"	65	867
96"	164	3090
144"	344	6679

M. Thinner Wall of CSP Reduces Excavation Cost

At most, the OD of CSP pipe is 2 1/4" greater than the nominal diameter. For RCP, the OD will be a minimum of 4" larger (12" pipe) and a maximum of 24" larger (144" pipe) than the nominal pipe diameter. This added wall thickness has an adverse impact on the number of pieces per truckload and on the width of trench needed for installation. The larger OD likely means more excavated material must be hauled off-site.

N. CSP Not as Susceptible to Handling Damage

RCP can be cracked or broken if not handled carefully, especially at the ends. RCP is very susceptible to impact damage such as that resulting from striking a hard object such as another concrete pipe. Damage to RCP usually occurs in the portion of the pipe incorporated into the joint. Concrete repairs made in the field are of questionable quality and durability. CSP is most susceptible to damage at its ends, but the initial shape of the pipe can be restored with relative ease. Damage along the barrel of a CSP can also be repaired.

O. RCP Must Crack in Order to Function

The concrete in RCP must crack in order to transfer tensile load to the reinforcing steel. This cracking occurs at four locations as noted in Figure 3, most importantly at the invert. The uncoated reinforcing steel is exposed to the environment where cracking occurs. Thus the steel in RCP is exposed to the same environmental conditions as the steel in CSP and subject to the same corrosive elements but without any protective coating.

P. Freeze-Thaw Cycles Damage RCP

The concrete in RCP is a porous material with voids that can fill with water. The invert of the pipe is the portion of the pipe most likely to have moisture present. If the pipe is subjected to repeated freeze-thaw cycles when moisture is present, the moisture in the concrete voids will expand and contract. This action damages the concrete and will eventually cause the concrete to deteriorate and spall. Spalling usually results in removal of the concrete cover over the reinforcing and exposes the steel to corrosion and abrasion.

Q. RCP More Susceptible to Sulfate and Chloride Attacks

RCP is subject to deterioration by sulfates and chlorides. The alkalinity of concrete makes it susceptible to attack by sulfates. Sulfates can occur in groundwater or effluent, but are typically found in alkali soils that occur in more arid (desert) regions. Concrete mixes should be specially designed or the pipe should be coated to increase resistance to sulfate attack.

Concrete is not especially susceptible to chloride attack, but the reinforcing steel is. The chloride source most detrimental to RCP comes from deicing salts used during winter months. Severe deterioration occurs when the pipe is in a minimal cover situation and the concrete is porous. The reinforcing steel in RCP is not coated so any chloride reaching the steel will immediately begin the corrosion cycle.

R. High Replacement Costs with RCP

Just as the installation costs for RCP are higher than CSP costs, replacement costs are also higher. If replacement of an RCP installation is required, the trench must be made wider, heavier pieces of pipe have to be removed, and more pieces must be handled. The same conditions apply to the installation of the replacement RCP. Rather than replace an existing RCP culvert with another RCP installation, the use of various smooth CSP, such as Spiral Rib pipe, as a lining for the RCP would be the preferable solution.

II. GOALS OF CSP PROMOTION

When promoting CSP against RCP or any other material, the following goals should guide the promotional efforts.

A. Fair Consideration of CSP

Many engineers and agencies have a bias against CSP, which means our goal is to convince them to give CSP equal consideration. Efforts aimed at having CSP specified for a project or being included in an agency specification, must address the reasons for the bias. Present the data fairly and accurately with a minimum of negative comments regarding the other material. To receive fair treatment, we must treat competing products fairly.

B. Use the Right Product for Each Application

Take advantage of the range of CSP products to ensure the right product is used. Just as galvanized CSP is not right for every situation, neither is a pipe with a premium coating. Build credibility by attempting to learn everything possible about a site and then recommending the best material. RCP has only one product to offer, while CSP has a wide variety of products as a result of available coatings.

C. Promote Life-Cycle Costing

When the project design life exceeds the estimated product service life, agencies should be encouraged to use “Life-Cycle Costs” to evaluate alternates. Even CSP with a premium coating will generally be considerably less costly than RCP. It is entirely possible that CSP can be rehabilitated at a future date and the total cost of installation and rehabilitation will be less costly than RCP. As rehabilitation and relining costs continue to decrease, life-cycle costs will put CSP in a more favorable position.

D. CSP as an Alternate to RCP

Be satisfied if promotional efforts result in CSP with a premium coating being specified as an alternate to RCP. Being an equal to RCP will generally mean that CSP will be the pipe material most often used. It is not necessary to be the only product specified in order to be successful in the marketplace.

III. THE BASIC PRODUCT

A. Reinforcing Steel

Concrete pipe can be furnished with or without reinforcing steel. Non-reinforced concrete pipe is not widely used and will not be discussed further. The vast majority of concrete pipe is reinforced concrete pipe (RCP), which typically has two layers of reinforcing steel as shown in Figure 1. The reinforcing is generally welded-wire fabric that has been rolled into two circular cages and placed near the inner and outer surfaces of the pipe. RCP gains its strength from the reinforcing that wraps circumferentially around the pipe. These cages are embedded in the pipe with ¾” or 1” of concrete cover over the steel. The reinforcing steel used in RCP is not coated. The area of steel is less than 3% of the cross-section area of the pipe wall.

Figure 1.

Double Circular Cages

B. Wall Thickness

RCP can be made in three wall thicknesses; Wall A, B or C. The project designer will typically not specify the wall thickness, but will let the RCP supplier decide on the thickness. The thickness furnished depends on the production equipment owned by the manufacturer, since most RCP manufacturers have equipment for only one wall thickness for each pipe diameter. For this reason, most RCP is manufactured as "B" wall because more precasters have this equipment. Wall "A" is ½" to 1"thinner and wall "C" is ¾" heavier than wall "B" pipe.

C. Changing Strength of Pipe

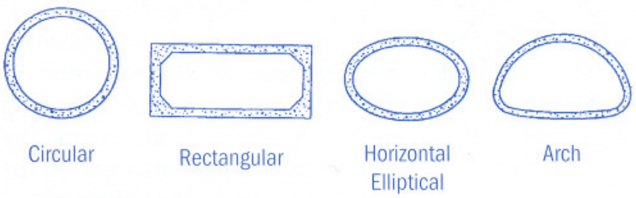
The strength of CSP is dependent upon the corrugation configuration and the wall thickness. The design strength of the steel in the pipe wall is constant. RCP is similar to CSP, but differs in that the strength of the concrete can be adjusted to achieve the optimum strength required. Like CSP, the design strength of the steel in RCP is also constant. Three factors enter into determining the strength of RCP. These are:

- **Thickness of pipe wall:** A thicker wall carries more load.
- **Strength of concrete:** Increasing the compressive strength of the concrete increases the pipe's load-carrying capacity.
- **Area of reinforcing steel:** Adding more steel to the pipe makes it stronger.

The last two methods of strength adjustment are most commonly used because the RCP manufacturer can only produce one wall thickness for each pipe size. A combination of increased concrete strength and the addition of more reinforcing steel is often used to increase pipe strength.

D. Shapes of Concrete Pipe

Concrete drainage products are available in four distinct shapes, as shown below. The shapes most commonly used are circular, elliptical and rectangular box culvert. The RCP elliptical shape can also be turned so as to have its larger dimension oriented vertically. This situation occurs infrequently. The rectangular section has largely replaced the arch shape. The box culvert section is designed so as to be installed with the pavement directly on the top surface of the box section. It is difficult to offer a CSP alternate for the box section designed with no cover.



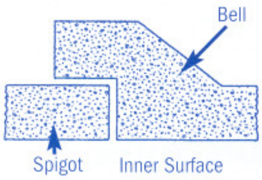
E. Non-Reinforced Concrete Pipe

Concrete pipe is also manufactured without reinforcing. Non-reinforced concrete pipe is available in sizes up to 36-inch diameter and is manufactured in three classes. The classes are Class 1, 2, and 3, with Class 3 having the highest strength. The differences between these classes are the wall thickness and the concrete strength. The wall thickness stated in ASTM C14 and AASHTO M86 for each pipe size are minimums. Non-reinforced pipe can be produced with a heavier wall and most manufacturers do make this pipe with the wall thickness specified for Class 2 and Class 3, because the thickness for these classes are the same. The ASTM and AASHTO specifications require a minimum strength, given in pounds per foot of length, for each pipe size and class. This strength is determined by the three-edge bearing test.

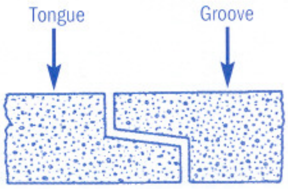
Non-reinforced concrete pipe is manufactured by the same methods used for reinforced pipe. The loads that can be imposed on non-reinforced pipe are considerably less than those on reinforced concrete pipe. Without the benefit of reinforcing, failures of non-reinforced concrete pipe are sudden and total. Any crack in a non-reinforced pipe is an indications of immediate collapse. Many agencies limit the use of non-reinforced concrete pipe to sizes no greater than 24 inch and limit the maximum cover to 15 feet with a shaped, granular bedding. Under similar installation conditions, non-reinforced concrete pipe has a strength equivalent to Class II reinforced pipe, a product that is rarely specified.

F. Joints in Concrete Pipe

RCP can be installed with high-performance joint systems involving o-rings, but these systems are typically not used for storm sewers. For most storm sewers and culverts, RCP joints will use mastic sealants or occasionally flat rubber gaskets. Joint configurations are basically a bell and spigot for smaller diameter and a tongue and groove for larger sizes. CSP joints may actually increase the pipe strength at the joint by the addition of the steel in the band. RCP joints are the weakest part of the pipe system because they generally reduce the pipe cross-section and may create corners that tend to crack when loaded.



Bell & Spigot Joint



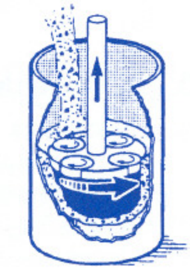
Tongue & Groove Joint

IV. SPECIFICATIONS

Description	ASTM	AASHTO
Non-Reinforced Concrete Pipe	C14	M86
Round RCP (Spec. by Class)	C76	M170
Arch RCP	C506	M206
Elliptical RCP	C507	M207
Round RCP (Spec. by D-Load)	C655	M242
Box Culverts (Cover ≥ 2 feet)	C789	M259
Box Culverts (Cover < 2 feet)	C850	M273
Watertight Joints	C443	M198
Soil-tight Joints	C990	M198
RCP Design (by SIDD Method)		Section 17
RCP Installation		Section 27

V. MANUFACTURE

Most RCP is made by one of two manufacturing processes. Round pipe, up to approximately 72" diameter, is machine made by the "Packerhead" process. This is a centrifugal process that uses a rotating head to pack a very dry concrete mix against an outer form. The rotating heads also finish off the interior of the pipe and give it a smooth surface. The pipe is lifted from the machine, the outer form that created the wall is removed and the pipe is self-supporting a few minutes after being manufactured. The pipe is supported on the bottom by the ring form that creates the bell or spigot end of the pipe. The pipe is cured overnight in a kiln and the next day is moved to the yard where it is exposed to the exterior environment. In cold or hot climates, the pipe will rarely achieve the concrete strengths indicated by tests on the concrete samples cured in controlled conditions.



Larger round pipe and all other shapes are typically manufactured by the "wet cast" method. This involves placing a normal concrete mix in a mold consisting of inner and outer forms. The concrete is cured overnight in the mold and removed from the mold the next day and placed in the yard where it is exposed to the environment and the ambient temperatures.

The reinforcing steel is placed in the mold, prior to introduction of the concrete for both production methods. Placement of the reinforcement is critical to pipe performance since the steel will carry all tensile loads. The steel in pipe made by the packerhead process, moves during manufacture and may not be at the specified location. Additionally, as the steel moves during manufacture, it can create voids along the longitudinal steel that ultimately allows water to reach the reinforcing and begin the corrosion process.

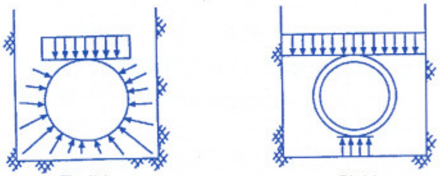
VI. STRUCTURAL DESIGN

A. Flexible vs. Rigid Pipe

RCP is designed as a rigid pipe as compared with CSP which is designed as a flexible pipe. The basic differences between flexible and rigid pipe design method are:

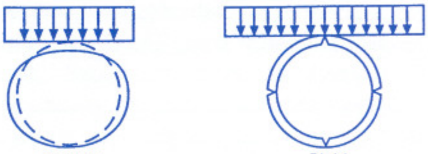
- Flexible pipe will deflect and transfer the load imposed on it to the soil surrounding the pipe. Flexible pipe carries only the weight of soil directly above it. As the flexible pipe deflects, the load on it is reduced due to soil arching, resulting in the transfer of the weight of soil over the pipe into the soil adjacent to the pipe.
- Rigid pipe does not deflect but merely transfers the load on it to the bedding beneath the pipe. The load on rigid pipe is greater than the soil directly above the pipe. This is a result of the transfer of load from the soil columns on each side of the pipe, to the pipe, as the soil columns beside the pipe settle and compact. *These conditions are shown in Figure 2.*

Figure 2.



- The structural design of CSP is based on shell theory. This means that the relatively thin wall of CSP acts like a thin shell. The load in all portions of CSP is a compressive load as a result of ring compression. Ring compression is also referred to as thrust.
- RCP is a unique rigid pipe because of its thick wall. The thick wall allows zones of tension and compression to develop within the pipe. Actually the thickness of RCP causes tension to develop on one surface of the pipe, such as the interior, and compressive forces to develop only a few inches away on the other surface of the wall, at the exterior. In areas where tension develops, the concrete will crack at which time the tension load is transferred to the reinforcing steel. The reinforcing steel in RCP does not contribute to the strength of the pipe until concrete cracks and tension is transferred to the steel. These cracks develop at the invert and crown on the interior of the pipe and at the springlines on the exterior. Thus rigid pipe (RCP) responds to load only after the concrete has been damaged and the reinforcing steel exposed to the environment. *These responses are shown in Figure 3. The notches on the rigid pipe show the tension zones.*

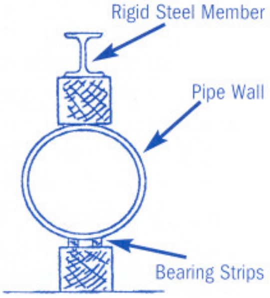
Figure 3.



B. Historical Design

The design concept for RCP has been continually evolving in an attempt to make it a more competitive product. For nearly 100 years, RCP has been designed based on the theory that the strength of the pipe was dependent on the width and quality of the contact between the pipe and the bedding. This is shown in Figure 2 for rigid pipe. The concrete pipe industry even developed a test called the Three-Edge–Bearing (TEB) test to simulate this design theory. Figure 4 shows a typical setup for this test. The pipe is loaded at the top and the two bearing points at the bottom approximate the support provided by the bedding. RCP design theory has changed but this test is still performed to establish the pipe's load carrying capacity.

Figure 4.



Historically, the design of RCP resulted in a specification of a specific "Class" of concrete pipe. Although RCP design has continued to evolve, many specifiers and engineers still specify RCP by class. Class refers to the load carrying capacity of RCP. The classes range from I through V, with Class V being the strongest pipe. A higher class RCP is equivalent to a heavier gage in CSP. Each class has the following strengths associated with it.

Class	D-Load (0.01" Crack)	D-Load (Ultimate)	Factor of Safety
I	800	1200	50%
II	1000	1500	50%
III	1350	2000	50%
IV	2000	3000	50%
V	3000	3750	25%

"D-Load" is the strength of RCP expressed in pounds per foot of diameter. Multiply the D-Load by the pipe diameter to obtain the load that each foot of pipe can support. For example, a Class IV, 24-inch diameter pipe, 8 feet long, must be able to carry 32,000 pounds (2000 x 2 feet x 8 feet). The D-Loads for RCP are determined by the TEB test. The strength listed under the first D-Load ($D_{0.01}$) column is the load the pipe must be able to support before developing a 0.01 inch crack. This crack is defined as one that is at least 0.01" wide, 1/16" deep and 12" long. The strengths given for the ultimate D-Load (D_{ult}) must be achieved before the pipe fails.

The concrete pipe industry argues that the 0.01-inch crack criteria was arbitrarily established many years ago and is not an indicator of structural performance. This is not totally true. The $D_{0.01}$ listed above equals or exceeds the total actual load calculated to be on the pipe. The "Concrete Pipe Handbook" (by ACPA) states "the safety factor, F.S., is defined as the relationship between D_{ult} and $D_{0.01}$. This would seem to establish a link between $D_{0.01}$, structural performance and the 0.01-inch crack since it is the indicator during the testing that the $D_{0.01}$ value has been achieved.

As stated earlier, the required strength of RCP is also dependent upon the quality of the bedding. By applying a "Bedding Factor," the required strength of the pipe is reduced. Even the worst quality of bedding, placing the pipe on a flat, unprepared subgrade, will reduce the required pipe strength by 9%. If RCP is installed on bedding similar to that required for CSP, the strength of the pipe need by only 2/3 of the load it must carry. If RCP were to be placed on bedding of concrete or CLSM, the required strength of the pipe could be reduced by 64%.

C. D-Load Design

In an effort to more closely match the pipe manufactured with the strength required, the concrete pipe industry developed the concept of specifying pipe by D-Load in lieu of class. The structural design of RCP results in calculation of a D-Load. The calculated D-Load is the basis for the selection of a pipe class, with the class selected having a D-load rating higher than the calculated value. This new concept allows the pipe to be specified by the calculated D-load. Using the D-load designation, a pipe specification might read "36 inch RCP, 1500 D-load." Previously, pipe supplied would have been Class IV (2000 D-Load). Now the pipe to be supplied would be 1500 D-Load, with a 25% reduction in load-carrying capacity and a lower price. The specified D-load will typically be the D0.01 value. The pipe manufacturer is required to design the pipe for the specified D-load and to conduct TEB tests to verify the design.

D. SIDD Method

The concrete pipe industry is now promoting a new design concept, intended to make RCP even more competitive. The new concept is called "SIDD," which is an acronym for Standard Installation Direct Design. This program is intended to match design with actual installation conditions. SIDD creates four standard installation conditions, with the difference being the quality of materials and compaction. Previous RCP design methods considered the quality of the bedding as the only aspect of installation that impacted the load capacity of the pipe. SIDD takes into account the quality of the bedding and the quality of the backfill up to the springline of the pipe. Backfill above the level of the pipe springline is of no importance and does not need to be compacted, unless under a roadway.

The new design concept is considered a soil-structure interaction condition, which makes the performance of RCP somewhat dependent on the quality of the soil envelope around the pipe. RCP design now more closely resembles CSP design. Lateral pressure has been ignored in previous design methods but is important in the SIDD method. Bedding for RCP is now specified to be loosely placed, uncompacted material for all four installation conditions, but the bedding factors vary depending on the installation condition and the pipe diameter.

Type 1 installation is the highest level of installation and requires compaction of a sand-gravel mix to 95% maximum density, up to the springline. Type 4 is the lowest level of installation and involves merely dumping all backfill material around the pipe with no compaction. Type 4 is being promoted as eliminating the need for an on-site inspector. Type 4 installation requires installation of a stronger pipe than would be required for Type 1.

SIDD is used to determined the load on the pipe. Once the load is determine, the pipe strength is calculated using the same procedure as used in earlier design methods. The advantage of SIDD is that it can significantly reduce the required strength of RCP, possibly as much as 40%. This makes RCP more competitive in the marketplace. In addition, the flexibility of trading off installation quality for material quality gives RCP an even greater advantage.

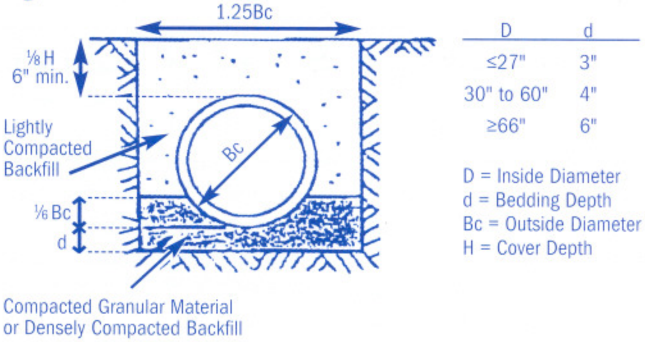
Fortunately, engineers and specifiers are slow to adopt new design theory. Many agencies are still specifying RCP by class and have not adopted the D-load method. The SIDD method will likely be accepted at a slower rate. Since FHWA was a partner in the development of SIDD, agencies may feel it has more validity. However, this design theory does raise certain basic questions. If bedding quality was deemed essential to RCP structural performance for more than 70 years, how can RCP installed on loose, uncompacted bedding, justify the use of lower strength pipe? Many agencies have had problems with RCP designed using existing design theories and will question the motives of these attempts to reduce the strength of pipe from levels determined using earlier design methods.

It is important that we make specifiers aware of these uncertainties. If the new design theory is valid, all RCP now installed has been over-designed. Given the number of RCP failures that have occurred, it is obvious that not all earlier RCP designs resulted in over-designed pipe. If the old design methods are valid, the RCP industry is attempting to enhance RCP performance with slight-of-hand methods that have questionable validity. Specifiers will be reluctance to accept new design theories that drastically change long-accepted methods.

VII. INSTALLATION

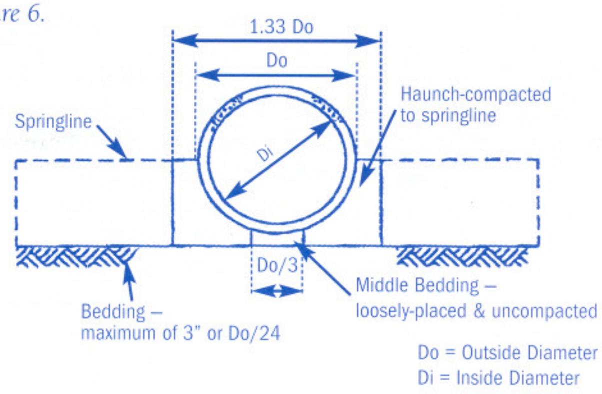
A discussion of concrete pipe installation must include a comparison of installation criteria under older and newer design methods. The older, proven design theories were based on the contribution of bedding to the pipe performance. Figure 5 depicts a Class C bedding, which will reduce the load on the pipe by approximately 33%. There is no specification for the backfill material or its compaction except the requirements for embankments placed under a roadway.

Figure 5.



A typical installation for the SIDD design method is shown in Figure 6. The bedding width is drastically reduced and the quality of the bedding has changed from a compacted material to a loosely-placed, uncompacted material. The bedding details are consistent throughout the four installation conditions. The overfill criteria are the same for all conditions, and require no compaction unless under a pavement. The changes in backfill requirements up to the pipe springline determine the installation type. Well-compacted quality backfill is called for in Type 1. The Type 4 backfill material does not require any compaction unless the material is sand and/or silt. Since the bedding is uncompacted, the soil envelope around the pipe can be totally uncompacted for a Type 4 installation.

Figure 6.



VIII. CONCRETE MATERIALS

The concrete mix in RCP is made up of cement, water, aggregates and possibly admixtures such as flyash. Each ingredient in the concrete mix is covered by an ASTM specification. However, like all concrete specifications there is no specification for the concrete mix used in RCP. The ASTM specs applicable to RCP, require only that the concrete mix have a minimum compressive strength. Some site conditions may require the use of a special mix design to increase density, reduce porosity or have the capability to resist certain deleterious environmental conditions.

Concrete pipe specifications do require a minimum cement content per cubic yard. Some manufacturers will increase the cement content above that required in order to increase strength, lower absorption and increase resistance to weathering, freeze-thaw, and certain chemical environments.

The strength in RCP comes from the reinforcing steel. If concrete pipe were made without reinforcing, much of it would not survive production and handling stresses. Most RCP suppliers use mesh reinforcing, with the heavier wire running circumferentially around the pipe. Specifications such as ASTM C76 that give reinforcing steel areas are referring to the circumferential wires. The main purpose of the lighter longitudinal wires is to hold the circumferential wires in place. The mesh is rolled into round cages and welded to give the cages dimensional uniformity.

IX. TESTING

CSP does not need to be tested in order to prove its structural capacity. RCP made in accordance with a "Class" design per ASTM C76 or AASHTO M170 does not need to be tested. Any concrete pipe product this is specially designed must be tested to verify that it satisfies the design requirement. The test utilized for this purpose is the TEB test discussed earlier. The test involves application of load at a uniform rate to the pipe until the 0.01-inch crack develops. The pipe is acceptable if the required unit load is achieved before the 0.01-inch crack develops.

X. DURABILITY (SERVICE LIFE)

"There are no definitive design methods for estimating concrete culvert service life. As a result, the designer must make judgements about the severity of the environmental conditions and the offsetting nature of a variety of design accommodations."[1] When asked about concrete pipe durability, a common reply from RCP industry people is that Roman concrete is still good after 2000 years. "Pipelines are beneath the ground where temperatures have very little variation, where atmospheric exposure is either not present or greatly reduced, and where the materials in close proximity to the pipe are usually non-aggressive."[2] CSP installed in these conditions would have a service life exceeding nearly all requirements. The service life assigned to RCP is a result solely of the designer's perception, formed on the basis of information provided by the concrete pipe industry.

In reality, there are a number of durability concerns related to concrete pipe. These include:

- **CRACKING:** The concrete must crack to transfer load to the reinforcing steel. When that happens, the steel is exposed to all the durability concerns that affect the durability of steel.

- **ACIDS:** If the pipe is exposed to pH less than 5.5, the concrete and subsequently the steel are susceptible to chemical corrosion. Protection can be provided by increasing the concrete cover over the steel or by providing protective coatings or linings.

- **CHLORIDES:** Chlorides that might come from de-icing salts or sea-water, can attack the reinforcing steel through cracks in the concrete.

- **SULFATES:** Sulfates, such as mine waste, are very damaging to concrete, and require special coatings or higher strength concrete.

- **FREEZE-THAW:** The porosity of concrete allows water to penetrate into the pipe walls. Repeated changes in temperature cause the water to go through freeze-thaw cycles that cause stress in the concrete. This leads to spalling or fracture of the concrete.

- **ABRASION:** Concrete pipe is subject to invert erosion as a result of abrasion. This generally occurs only when large bedload is carried through RCP at a high velocity.

References:

1. AASHTO Highway Drainage Guidelines, Volume 14.

2. Concrete Pipe Hand book, American Concrete Pipe Association