NATIONAL CORRUGATED STEEL PIPE ASSOCIATION **ISSUED: March 2001**

Competitive*products*

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MEMBERS ONLY

HDPE Pipe

I. Promoting Against HDPE

Promoting against HDPE pipe can be a difficult process at best. The most common approach taken by the HDPE industry is to promote their product as a material that combines all of the advantages of the products that have historically been used for drainage pipe at a much lower cost. In addition, the industry has promoted it's lightweight and perceived installation ease.

The CSP industry is put in the position of not only defending our product, but attempting to shed some light on the misinformation surrounding HDPE pipe. If not handled carefully, this can be construed as negative selling. Any discussion should be brought out as a comparison of the two products.

A. Durability

Unlike CSP, which is well understood and has been thoroughly evaluated, the durability of HDPE is an extremely complex and essentially unknown topic. A review of nationally published durability documents provides little or no relevant information on the service life of this product. There are no accepted methods for estimating the service life of HDPE. Service life values assigned by agencies appear arbitrary with little or no justification.

In reality, HDPE considerations must evaluate both the durability of the HDPE material as well as the durability of the entire pipe system. In comparison, CSP durability is generally limited to materials issues (abrasion and corrosion). Even under conditions that can cause material deterioration in the invert, CSP most often will not suffer system function. In addition, numerous coatings are available for CSP products which result in excellent material durability even under extreme environmental conditions.

HDPE, on the other hand, suffers from numerous, complex materials issues that also impact the function of the pipe system. HDPE material durability issues include: environmental stress cracking in the form of slow crack growth and rapid crack growth, tearing, buckling, deflection, antioxidants issues, and UV degradation. While corrosion and abrasion may not be an independent weakness, the combined effects with other material issues may be significant.

All of these issues have the potential to affect the durability of HDPE to function as a system resulting in cracking, buckling, deflection, and reduction in hydraulic performance. Combined with installation sensitivity, the long-term structural durability of HDPE materials continues to be an unknown quantity. A strong case can be made for the proven long-term structural performance of CSP vs. the unproven long-term performance of HDPE.

Specifiers and users need to be made aware of the ongoing research into HDPE products. Studies include investigations of circumferential cracking, resin quality and in-service hydraulics. Of significant interest is the National Cooperative Research Program (NCHRP) Project 4-24, published as Report 429. This study was undertaken "... to evaluate the stress crack resistance (SCR) of high density polyethylene (HDPE) corrugated pipes and correlate it with observed field performance." The project identified sites where cracking in HDPE pipes had been observed, sampled the pipe materials from 19 field sites and sampled 14 commercially new pipe materials to investigate the SCR of the materials. Findings included:

- Of 33 samples, 19 failed to meet the tests for Stress Crack Resistance.
- 17 of the samples failed to meet the spec for carbon black content.
- Overall, more than 82% of the pipes sampled did not meet AASHTO specifications for HDPE pipe.

In addition, some D.O.T.'s have assigned limited service life to HDPE pipe. All of this information should and can be used to build a case for a higher service life for CSP products.

B. Structural Design

HDPE pipe and CSP are both designed as flexible pipe systems. In a flexible pipe, the pipe deflects, transferring the load imposed on it to the surrounding soil.

Historically, plastic pipe design methods involve checking the pipe for deflection, wall buckling and wall crushing. Deflection is typically checked using Spangler's Iowa Deflection Formula in one form or another. This formula incorporates the load on the pipe, pipe stiffness, pipe diameter as well as factors for the backfill material and bedding. Buckling and crushing are checked based upon the material properties and cross-sectional properties of the pipe wall.

A point of significant debate and discussion is the properties that are being used in HDPE pipe design. Currently HDPE thrust limitations are based on a long term strength level derived from a stress rated resin no longer required. A lack of knowledge of the long-term properties of the material lead to inadequate designs or installations.

HDPE pipe manufacturers have pushed for consideration of circumferential shortening and thus reducing the ultimate design load on the pipe. Under the ring compression load, some studies have shown that the pipe circumference actually shortens. As a result, the soil over the pipe arches and reduces the overall load on the pipe. While this concept is a valid one, there are negative effects on the overall pipe structure. Field installations demonstrate that circumferential shortening is one of the causes of liner waves (local buckling) and circumferential cracking.

AASHTO recently adopted a design method that accounts for this load relief. The design method, which was developed with funds from the National Corrugated Polyethylene Pipe Association (NCPPA), actually reduces the soil load "felt" by corrugated HDPE pipes to 30 to 80% of the actual soil prism load. However, even this design method has not been well received by the polyethylene pipe industry. While load relief has been recognized, the new AASHTO also recognizes the compression strains involved and how they lead to local buckling considerations that further limit overall load carrying capability.

The local buckling portion of the new AASHTO design method was developed under a National Cooperative Highway Research Program study, NCHRP 20-7, Task 89. Local buckling occurs when a portion of the pipe corrugation buckles independently and can no longer carry load. To control local buckling, M 294 pipes are limited to 50 to 70% of the capacity once attributed to them. Additionally, to control critical compression strains, backfill materials and their density often must be improved and pipe deflection limited.

The new AASHTO Design method takes an in depth look at the combination of the properties of the plastic, the geometry of the pipe wall (corrugation), the deflection that occurs in the pipe and the soil properties of the backfill envelope. The end result is an overall decrease in allowable heights of cover using the standard silty sand (A2-4/A2-5) AASHTO backfill materials compacted to the minimum AASHTO density. While clean sand and gravel (A1 and A3) backfills can provide increased cover capabilities, this generally comes at the expense of higher compaction levels, and can require an increased backfill width to support the soil arch.

The roll of deflection is significant to both the design and field performance of polyethylene pipe. With the more critical backfill requirements, on site inspection is a must as is mandrel testing to affirm deflection levels assumed in design as well as to ensure construction quality.

Local buckling, where individual elements within the wall profile buckle and can no longer carry ring compression, is the combined result of circumferential shortening and deflection bending. Local buckling leads to reduced load carrying capacity, loss of hydraulics "smoothness", strain cracking, and ultimately failure.

NCHRP 20-7, Task 89 demonstrates this combined effect. Backfill stiffness, controlled by backfill quality and its compaction level, is a major factor. However, the study demonstrates that even with backfill well beyond AASHTO requirements, deflection often must be limited to levels in the range of 3% to control failure. There are levels well below these that can readily be achieved with these low stiffness pipes.

CSP on the other hand has long been forced to meet requirements that alleviate local buckling considerations.

Even following the NCHRP recommended design procedures, stringent backfill control (field inspection) and pass-fail deflection testing is a must to ensure long term performance.

C. Hydraulics

Again, the long-term performance of the system must be brought into consideration. While HDPE products have shown excellent hydraulic characteristics in laboratory testing, there have been developments regarding the in-place hydraulics of HDPE pipe. NCSPA Technical Note No. 197 – "In-Service Hydraulic Characteristics of Corrugated Polyethylene Pipe with a Smooth Interior" provides information on this issue. Included is a nomograph for estimating the in-service roughness of smooth-lined corrugated PE pipe. In short, under loading, the interior of the pipe begins to exhibit "waves." A 36" diameter HDPE pipe with 0.5" deep waves has an in-service Manning's "N" of 0.022. This means the pipe has an in-service flow capacity that is 40% lower than the design value.

Given this, CSP should not be given a hydraulic disadvantage, as is done in many cases. Instead, CSP is hydraulically superior in small diameters and in many wall and lining configurations.

D. CSP is not UV & Temperature Sensitive Like HDPE

Everyone knows that the primary effect of sunlight on steel is to increase the material temperature. This does not change steel's properties. Plastic on the other hand, is extremely sensitive to UV degradation. When raw resin is exposed to UV rays, degradation can occur fairly rapidly. Plastics that are going to be exposed to UV rays are typically treated with inhibitors such as carbon black. While these inhibitors are beneficial, continued exposure will still result in a breakdown of the material. Culvert applications offer continued exposure to UV degradation. It is also important to note that for the NCHRP 4-24 pipes sampled, 57% of the new pipe failed to meet the minimum required carbon black content.

HDPE is by definition a thermoplastic material. As the material temperature increases, the plasticity or softness also goes up. HDPE pipes sitting in the hot sun on a summer job site experience a significant reduction in pipe stiffness due to the increased material temperature. While CSP will increase in temperature, the pipe has no significant loss of stiffness. It does not become more difficult to install.

E. Compare the Installed Costs

One of the strong points of HDPE is its low material cost. However, the cost of the installed system should be considered when making a comparison. Historical AASHTO Section 30 limits have been increased by the new AASHTO design requirements. Typically Backfill materials are clean sands and gravels (A1 or A3) compacted to densities above the minimum AASHTO 90% level. Backfill widths of one diameter on each side of the pipe are often necessary for covers of more than 10 feet.

CSP requirements haven't changed. It retains its minimum cover advantage and now is typically used with poorer grades of backfill. Pipe deflection is not a design or service limiting consideration for steel pipes. Deflection testing is not required.

AASHTO Section 30 limits the bedding and structural backfill material of Thermoplastic Pipe to A-1, A-2-4, A-2-5 and A-3. These materials are essentially clean gravels and sands. In addition, Section 30 calls for a minimum cover over the pipe of 24 inches. CSP requires a minimum cover of 12 inches or 1/8 diameter whichever is greater.

In areas of low cover, below 24", HDPE pipe should not be used. Section 30 also requires a 5% deflection limit after 30 days. This implies that a mandrel test is required and mandatory repair when the limit is exceeded.

F. CSP Holds a Better Alignment During Installation

All CSP manufacturers understand the importance of beam strength or longitudinal stiffness. HDPE pipe is much more flexible along it's longitudinal axis than CSP. As a result, the compactive effort required to properly install the product can also result in an installation with a poor horizontal alignment. The vertical alignment can also suffer when the supporting strength of the bedding and subgrade is not uniform. CSP's higher beam strength and longer joint length, has always been a positive point when bridging a soft spot in the subgrade.

G. Buoyancy

While all buried structures are subject to buoyant forces, the structure and composition of HDPE pipe make it more susceptible to floating than CSP.

HDPE has a specific gravity that is less than water. A solid block of HDPE material will float. Combine this with the closed cell construction of smooth lined HDPE pipe and the result is a highly buoyant structure. This problem is exacerbated further by the low beam strength of the pipe. CSP's beam strength is much higher and therefore can rely on the total length of the backfill on top of the pipe to resist the buoyant forces. HDPE pipe, because of it's buoyancy and higher longitudinal flexibility, has shown a tendency to "pop out" of the ground in locations where the backfill is not adequately loading the pipe. This can be especially aggravated at the pipe joints or at the ends of culverts.

H. Don't just consider the laboratory performance of joints.

The HDPE industry has begun promoting a "water-tight" joint in accordance with ASTM D3212 (w/ exceptions to 30" – 60" sizes). While a laboratory test may yield this performance, anyone who has "crawled" pipe knows that deflected joints will not yield this high performance.

Specifiers need to think about the function of the system and the need for a "water-tight" pressure tested joint. This type of specification is typically used in the sanitary sewer industry to reduce infiltration into the piping system, not exfiltration into the backfill. Infiltration means more water to treat at the sewage treatment plant.

The function of a joint in a storm sewer system should be to prevent the migration of backfill into the pipe. Infiltration of water into the pipe can be considered a good thing.

Standard CSP joints have a history of providing the performance that is necessary in a storm sewer system.

I. CSP's History of Performance Vs HDPE J. Means More Inspection

HDPE has a significantly shorter use history than CSP. However, it has already shown some problems with field installations. Many agencies require stricter inspection of HDPE. Specifically, they require pulling a deflection mandrel.

Mandrel tests are important to HDPE because of it's limited history, as well as the time sensitivity of it's material properties. Ideally, deflection inspections should be performed 30-60 days after installation and again approximately one (1) year after installation

J. Crawl the Pipe

Especially for a new material, the only way to truly ascertain a it's long-term performance is to look at the pipe after it's been in the ground for a period of time. Ask the average designer if he/ she has looked at any of their pipe installations a year later and the answer all too often is no.

The specifying community needs to see the problems first hand. AASHTO has made a major change in its design and installation requirements for HDPE pipe 15 years after it first provided for its design. Certainly they have recognized a problem and have taken action. How well will these new designs fair with the necessary increase in field control? Only time will tell. **They must be seen first hand by crawling the pipe!**

II. The Basic Product

A. History

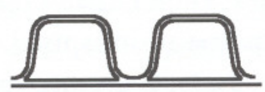
Use of Corrugated High-Density Polyethylene pipe for drainage applications began approximately 30 years ago with small diameter (4" – 12") pipe. By the mid to late 1980's HDPE manufacturer's were marketing pipe diameters up to 24". The 90's have seen the largest growth in the HDPE pipe industry. HDPE manufacturers have introduced large diameter pipe (up to 60") and new joining systems including water tight bell and spigot joints. The growth in HDPE sales has been phenomenal. Presently, the two largest manufacturers of corrugated HDPE pipe in North America have approximately 40 manufacturing facilities between them.

B. Types

The majority of HDPE storm drainage pipe is manufactured with a corrugated exterior. The interior of the pipe can either be corrugated or smooth depending upon the hydraulic characteristics desired. One major manufacturer produces large diameter pipe (42" & 48") pipe with a closed cell configuration resulting in a smooth interior and exterior.

Sizes range from 3" to 60" depending upon the manufacturer. Small diameter HDPE is commonly used for underdrain systems and foundation drains.

Corrugated Interior

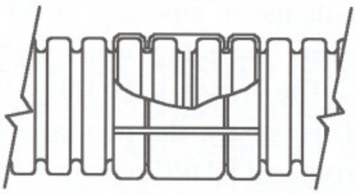


Smooth Interior

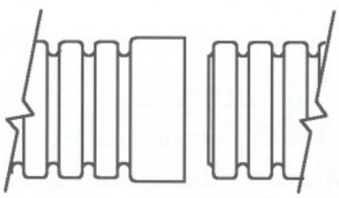
C. Joints

Joining HDPE pipe is typically accomplished by one of two methods. A split coupler or connecting band consists of a corrugated coupler with one or two "hinge points" and a connection point. The connection point is held together with plastic or wire ties. Split couplers are low cost and offer the advantage of allowing the installer to join two pieces of field cut pipe.

The 1990's saw the development of bell and spigot joints by most HDPE pipe manufacturers. Some of the bell and spigot joints are held in place by a friction (tight fit) coupling while others have employed a set of tabs that index into the first or second corrugation of the pipe.



Split Coupler



Bell & Spigot

HDPE joining systems offer gasketed joints using neoprene or expanded rubber gaskets. HDPE pipe manufacturers are promoting water tight joints with a 10 psi rating in accordance with ASTM D3212 for smaller sizes and a 5 psi rating for sizes 30" – 60".

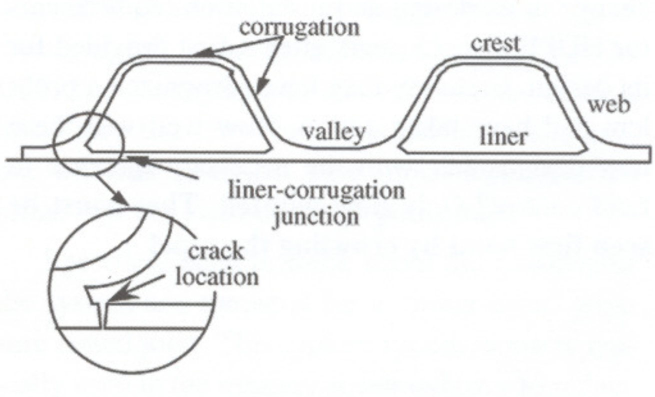
D. Resins

The basic building block of HDPE pipe is the high-density polyethylene resin. Polyethylene is a petroleum-based product consisting of long chain carbon molecules. High Density refers to the unit weight. Polyethylene resin is used in the production of many products, consumer and construction alike.

Simply specifying a product as HDPE, leaves it open to a wide variety of plastics quality. Plastic is usually specified further by its cell classification. ASTM D 3350 provides an explanation of cell classification for polyethylene pipe and the required material tests. An HDPE cell classification is a series of six numbers (i.e.- 335420C) that refer to minimum test values that must be met when testing the physical properties of a resin.

Of specific interest, and a point of recent controversy, is the Hydrostatic Design Basis (HDB) of the resin. Historically, HDB has been used to determine the materials ability to withstand long-term stresses. However, in recent years, the HDB requirement was removed from AASHTO Section 18 "Soil-Thermoplastic Pipe Interaction Systems." It was argued that corrugated HDPE pipe is not subject to the tensile stresses measured in an HDB test.

According to the NCHRP Project 4-24, "materials that comply the basic property requirements, such as density and HDPE drainage pipe materials need to be selected that have adequate resistance to crack initiation and propagation while subjected to sustained loading. This expectation is not adequately addressed within the current AASHTO specifications, which do not satisfactorily deal with HDPE's nonlinear strain reaction to stress. Materials exhibiting low ductility can fail prematurely in a crack like fashion (brittle fracture) brought on by a process called "slow crack growth." Materials with inadequate long-term strain capacity need to be excluded from use in HDPE drainage pipes."



Location of circumferential cracking.

III. Specifications

Specifications applicable to HDPE pipe:

- **AASHTO Standard Specifications for Highway Bridges**

Section 18:	Soil-Thermoplastic Pipe Interaction Systems
Section 26:	Metal Culverts
Section 30:	Thermoplastic Pipe

- **AASHTO Materials Specifications**

M252:	Corrugated Polyethylene Drainage Pipe
M294:	Corrugated Polyethylene Pipe, 300-1200 mm

- **ASTM Specification**

F405:	Corrugated Polyethylene (PE) Pipe and Fittings
F667:	Large Diameter Corrugated Polyethylene Pipe and Fittings
D2321:	Underground Installation of Flexible Thermoplastic Sewer Pipe
D2412:	Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
D3350:	Polyethylene Plastics Pipe and Fittings Material

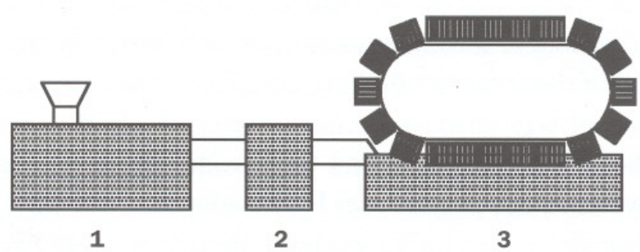
IV. Manufacture

HDPE pipe is manufactured with either helical or annular corrugations. The corrugation pattern is a result of the manufacturing process.

Helically corrugated pipe is manufactured by extruding a specific strip width of plastic that is then helically wrapped around a mandrel of a specific diameter. The result is a pipe with helical corrugations similar to the helical corrugations of CSP.

HDPE pipe with annular corrugations is manufactured by extruding a tube of HDPE that is then corrugated by a series molds or dies. As the HDPE is extruded, the molds clamp onto the outside and a vacuum or forced air is used to draw or expand the plastic into the form. When a smooth lined pipe is desired, an interior liner is extruded along with the exterior shell. The liner is formed against an interior mandrel to help maintain the shape and diameter of the pipe.

Manufacturing Process



1. Extruder melts and "extrudes molten plastic.
2. Extruder Die introduces molten plastic into corrugator
3. Corrugator molds plastic using a set of rotating mold blocks.

V. Testing

Testing of HDPE pipe includes testing base material to develop a cell classification per ASTM D3350 and pipe stiffness testing per ASTM D2412.

A. Cell Classification

ASTM D3350 provides for testing the density, melt index, flexural modulus, tensile strength at yield, environmental stress crack resistance and hydrostatic design basis as well as indicating the color and UV stabilization used in the material. The values obtained from these tests are used to develop a cell classification for the HDPE material.

B. Pipe Stiffness

In ASTM D2412 "A short length of pipe is loaded between two rigid parallel flat plates at a controlled rate of approach to one another." Stiffness is the measure of the load required to deflect the pipe a given amount at a specific rate of deflection. While pipe stiffness has been a major point of discussion when comparing HDPE pipe with CSP, care should be taken to understand these numbers. D2412 provides only a laboratory stiffness. A polyethylene pipe's actual stiffness during installation is generally much lower.

VI. Durability (Service Life)

The HDPE industry has argued that "Durability issues center on resistance to electrochemical corrosion (rust),chemical corrosion, abrasion, or a combination of these factors." While all of these factors do have an effect on the service life of a product, durability or service life discussions must be expanded to consider those issues which are appropriate to HDPE material, not CSP. Durability must also evaluate the piping systems ability to perform the function it was designed for over the required life of the project.

As stated above, there is no definitive method for determining the service life of HDPE pipe, yet there are numerous, complex issues surrounding durability. Given the relatively short usage of the product (30 years) long-term structural and hydraulic performance is still unknown. Studies are underway or planned to try and develop some criteria for these issues, however, CSP's long proven history of in-ground performance should be viewed as a positive.

References

LRFD Specifications for Plastic Pipe and Culverts, NCHRP 20-7, Task 89 Final Report, T.J. McGrath and V.E. Sagan, March 1999.

HDPE Pipe Material Specifications and Design Requirements: Final Report, NCHRP Project 4-24, Y.G. Hsuan and T.J. McGrath, March 1999.

Drainage Technology Bulletin: HDPE Pipe Material Specifications and Design Requirements, National Corrugated Steel Pipe Association, October,1999.

In-Service Hydraulic Characteristics of Corrugated Polyethylene Pipe with a "Smooth" Interior, Technical Note 197, National Corrugated Steel Pipe Association, August, 1994.