

READ between the PIPES

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Concrete pipe offers safety benefits
when used in storm sewer systems

The engineer's role in any design project is to design a project that meets the desired purpose, is constructible and ensures the health, safety and welfare of the user. However, engineers do not always recognize the consequences of their designs.

Civil engineering is a profession that holds life and death consequences. When engineers design a project, an error or mistake could result in property damage, personal injury or even death. Not understanding a product, while allowing its use, may equate to negligence if injury results. Not reading the product literature also may constitute negligence, should the product's failure result in injury or damage. When products fail, the engineer may be deemed the responsible party.

Many engineers do not understand or appreciate the differences between reinforced concrete pipe (RCP) and high-density polyethylene (HDPE) pipe and the potential for liability when specifying each product. While RCP is a rigid structure that is designed, built and tested as a structure before it arrives at the construction site, the structure of HDPE pipe is actually built and tested in the field. Therefore, HDPE pipe is not an "approved equal" substitute for RCP.

If a design is found to be faulty and there is injury to either property or to a person, and the engineer is found not to have met his or her standard of care, then the engineer is deemed negligent. This could result in not only monetary damages, but ultimately in the loss of the engineer's license. Additionally, the engineer may be criminally responsible for any death(s) caused by poor engineering. While engineers typically are not legally trained, any engineer who stamps a drawing certifying that a design will meet the intended purpose of the contract should understand the concepts of standard of care, negligence and liability.

Why specify?

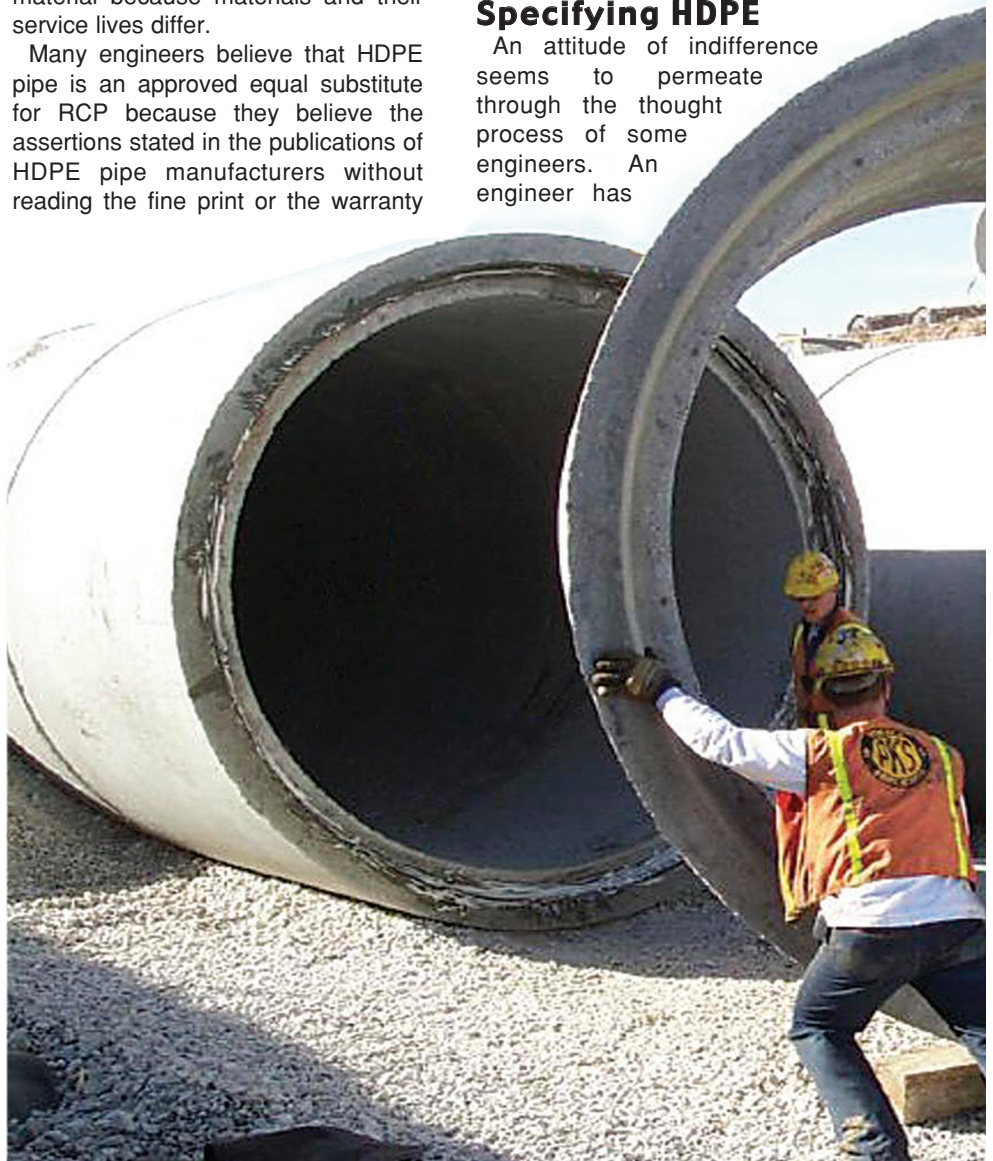
Corrugated HDPE pipe, rather than RCP, is typically specified by design engineers as a result of assertions by HDPE pipe manufacturers regarding its lower cost and superior attributes. In some cases, HDPE may be a reasonable alternative to RCP, depending on the specific project requirements and design life. However, designers must be cognizant of all aspects and design responsibilities of using any pipe material before specifying that material because materials and their service lives differ.

Many engineers believe that HDPE pipe is an approved equal substitute for RCP because they believe the assertions stated in the publications of HDPE pipe manufacturers without reading the fine print or the warranty

information. The advertisements by HDPE pipe manufacturers can be tempting to the engineer as a perceived means of achieving reduced cost and time of construction. In addition, assertions made by the Plastic Pipe Institute on service life also may provide the engineer assurance that the product specified will indeed last a minimum of 100 years. Yet, these manufactures' own warranties and other disclaimers do not support these assertions.

Specifying HDPE

An attitude of indifference seems to permeate through the thought process of some engineers. An engineer has





Nesting large RCP on radius.

the legal responsibility to determine whether or not the product being specified will perform its intended function for the specific project in which the design is performed. Therefore, before specifying a particular product, the engineer must be aware of the characteristics, applications, potential deficiencies and limitations of the product. If the product is determined to have been unsuitable and damages result, the engineer may be deemed negligent and damages will be assessed against him.

Engineers have a duty to exercise reasonable professional skill and judgment and must adhere to the standard of care ordinarily exercised by members of their profession. The duty to adhere to the profession's standard of care requires the engineer to use reasonable diligence and best judgment, which includes guarding against omissions or defects in plans and specifications and keeping abreast of improvements.

To apply one's best judgment, one must fully understand the differences between HDPE pipe material and the RCP structure when deciding which to use. Before selecting HDPE pipe, the engineer must review the specified products and their performance for in-situ conditions and evaluate available literature to ensure that the proper considerations are being made. The engineer must be wise to distinguish manufacturers' claims from actual facts regarding their products.

Reasonable diligence also requires engineers to have read and understood the most recent ASTM and

AASHTO standards in order to ensure that the design considers all aspects of both the standards' requirements, as well as the recommendations of those standards. Some ASTM/AASHTO specifications place significant responsibility on the engineer regarding installation essentials to ensure service performance. Applicable sections in ASTM D 2321-04 include requirements placed on the engineer with regard to installing thermoplastic pipe.

Engineers also must recognize that HDPE pipe requires an engineered installation in which the engineer must be involved in the construction activities. The engineer must take responsibility to ensure that post-installation deflection testing has been performed and documented. Before making a final recommendation to the client, the engineer has a responsibility to analyze life-cycle costs, the risks associated with the chosen pipe product and to inform the client about the short-term and long-term costs, as well as any further risks that are identified during the selection of the pipe material.

HDPE vs. RCP

Manufacturer publications are a small part of what engineers should be relying on when determining whether or not to specify corrugated HDPE pipe. One of the most important aspects that engineers must understand before specifying corrugated HDPE pipe is the vast engineering differences between HDPE pipe and RCP.

Design of any pipe system requires knowledge of material properties,

installation conditions and external loads. All of these elements combine to define the behavior of the installed pipe.

RCP is a load-bearing rigid structure, and a single length of RCP is designed, built and tested as a structure before it arrives at the construction site. In addition, the American Concrete Pipe Association (ACPA) has published the *Concrete Pipe Design Manual* since 1970. This manual contains engineering data on the hydraulics, loads and supporting strengths and design of concrete pipe.

HDPE pipe is a flexible material and is not an independent structure. In a corrugated HDPE pipe system, the vertical load is transferred to the side support soil and must deflect to function. Specifying corrugated HDPE requires the engineer to provide a different design than when specifying RCP. Therefore, HDPE is not a material alternative to RCP and cannot be interchanged in the design.

Factors that determine the success of an underground installation extend well beyond the attributes of the pipe material and product itself. The quality of the environment around the buried pipe is crucial to the long-term performance of the piping system. That is because buried plastic pipe is a composite structure made up of the plastic ring and the soil envelope. Both the ring and soil play a vital role in the structural design of plastic pipe. Corrugated HDPE pipe installed underground, being a flexible conduit, deflects under load and interacts structurally with the surrounding soil embedment material. Deflection is the change in the inside diameter that results when a load is applied to a flexible pipe. The deflection characteristics are a prime consideration in the structural design.

Engineers must use the soil to construct an envelope of supporting material around the pipe so that the vertical load, applied to the side soil through pipe deflection, is adequately supported. The extent to which the pipe depends on this enveloping soil for support is a function of the depth of cover, surface loading and the ring stiffness of the pipe. This pipe-soil interaction provides the necessary long-term support for the pipe. Therefore, the prime structure in an HDPE pipe system is the soil envelope.

Because HDPE pipe is soil-dependen-

dent, the behavior of the pipe-soil system requires a determination of the interaction that will occur between the pipe, embedment material and the native soil. The sum of these components acting together determines the total system behavior. Because the soil in the HDPE pipe-soil interaction can account for up to 90% of an installation's success, it is critical that this determination be made by a geotechnical or soils engineer.

Embedment refers to the material immediately surrounding the pipe. The embedment material must provide adequate strength, stiffness, uniformity of contact and stability to minimize deformation of the pipe due to earth pressures. The amount of resistance found in the embedment soil is a direct consequence of the installation procedure—the stiffer the embedment materials, the less deflection.

Controlled low-strength material, also referred to as flowable fills or controlled-density fill may be used for backfill and bedding, provided adequate flotation resistance can be achieved by restraints, weighting or placement technique. Designers must calculate the width of the trench required to provide sufficient structural strength for the system. Minimum trench width is a function of pipe diameter, backfill material and the compaction technique. The engineer must consider not only the embedment material, but also the undisturbed in-situ soil surrounding the embedment and the groundwater. The in-situ soil in the trench wall can migrate through the embedment and affect the pipe's performance.

The HDPE pipe structure is actually built and tested in the field. The resultant deflection of the flexible pipe is directly dependent upon the system's behavior. Deflection of HDPE pipe must be controlled by the stiffness of the pipe, variations in the pipe wall thickness or profile, stiffness of the soil embedment, type of shoring system used, water table, means and methods of the contractor, pipe handling, compaction control, inspection and temperature. Therefore, testing for excessive deflection is not a quality-control check of the pipe, but the only way to ensure that the pipe was properly installed with the soil envelope fully developed.

Research has shown that it takes substantial time—months to years—for the full load to reach the pipe in either

the trench or embankment conditions. When long-term tests are carried out in trenches and embankments, the changes in deflection with time are due to increasing loads and soil consolidation. The strength of the HDPE pipe material reduces under sustained loads as well.

Deflection, as well as other HDPE pipe performance criteria, is a critical long-term performance phenomenon. Typically, acceptance deflection is measured after the pipe has been installed and backfilled for at least 30 days. This gives the soil initial time to settle and stabilize, although additional changes are certain to occur and inspections should be written into the plans. When HDPE pipe exceeds its deflection-acceptance limit, it should be uncovered and the embedment material replaced and compacted. Specifications should also require that the pipe be removed and replaced.

Recently, the Florida Department of Transportation (FDOT) changed its specifications to require that all pipes be videotaped with laser-profile technology. The inspection applies to all pipes with a 48-in. diam. and less, except side drains and cross drains that are short enough to inspect from each end. The requirements include, among other things, a pipe ovality report, deflection measurements with graphical diameter analysis and a flat analysis report.

The key factors affecting the success of an HDPE pipe installation include:

- Recognition that corrugated HDPE pipe itself is not a structure like RCP;
- Recognition of a soil/pipe interaction in the design;
- Chemical composition of the polyethylene;
- Proper installation techniques; and
- Conclusive evidence that the proven service life of the product matches the design life of the project.

Read the fine print

Manufacturer information, warranties, standards and specifications are written to caution, warn and instruct the user about the specific material, product or design to be performed. When the author asked engineers whether they have read the fine print of a manufacturer's product information or the applicable national or

state standards and specifications, the answer has often been "no." However, when provided to engineers, the detail found in these types of reference materials often incurs a reaction of shock relative to what he or she may have specified without understanding the consequences of that action.

HDPE pipe manufacturers' warranties make it clear that no warranty is made if the product is not used for the particular intended use. One manufacturer's warranty notes that the HDPE pipe warranty is for the material, and that the material conforms to ASTM and AASHTO. Significantly, the warranty does not discuss the use of the material as a structure.

Other manufacturers provide the disclaimer that, even though the manufacturer offers directions, recommendations or suggestions for the use of their products, it is solely the buyer's responsibility to determine whether the product is suited for the specific needs of the buyer. Some state that the buyer assumes all risk for unloading, discharge, storage, handling and installation, and that they will not be responsible or liable for any removal or installation costs, downtime or other consequential damages, even if they have been advised of the possibility of such damages.

Facing consequences

While not all corrugated HDPE pipe failures end up in law suits and litigation, some do. It is not just the contractor or HDPE pipe manufacturer that finds itself potentially liable, but also the engineer. The following reasons have been borne out in law suits and controversies over the last decade:

- Failure to understand or perform life-cycle cost analysis;
- Failure to recognize and understand the differences in pipe design, installation and inspection between HDPE and RCP;
- Assuming that HDPE pipe is merely a substitute product for concrete pipe;
- Persuaded by HDPE pipe manufacturer publications touting benefits of HDPE compared with concrete pipe;
- Reliance on HDPE pipe manufacturer publications without an analysis of the specific project conditions and circumstances; and
- Assuming that he or she is bullet

proof and that professional liability insurance will cover any problems or issues arising at the site and that site problems are solely the result of issues of the manufacturer or the contractor.

One of the more costly examples of HDPE failure occurred in Shell Lake, Wis., in 2003. Shell Lake is the largest land-locked lake without an outlet in the state of Wisconsin and is approximately 2,580 acres in size. Because the lake has no surface water outlet, the city of Shell Lake commissioned a local civil engineering firm to design a combination gravity/siphon discharge from Shell Lake to the Yellow River, a distance of approximately 4.4 miles. The purpose of the pipeline was to allow the city to lower the elevation of Shell Lake during periods of high water. The project bid resulted in a system of corrugated HDPE pipe with a liner.

The pipeline was installed in November 2002 and began leaking in January 2003. The leaks continued and numerous attempts were made to fix the leaks; each time, the gravity/siphon discharge system was shut down.

While the discharge system was shut down in May 2003, heavy rains caused the lake level to rise with no way to discharge the rising water. Severe flooding and water damage was experienced by 120 of the lake's 380 residents. Law suits were filed against the pipe manufacturer for negligent manufacturing of pipe products and supplying pipe products that were defective and unsuitable for the intended application. The contractor was sued for negligently retaining and training persons on the project performing the installation. The engineer was sued for negligently designing and engineering the project, approving unnecessary or harmful changes to the plan and approving the pipe product. The suit was eventually settled, but at a cost of approximately \$1.25 million. The engineer and his insurers agreed to pay a significant proportion of that settlement.

Learning from errors

As a result of failures like Shell Lake, many municipalities and state agencies are either discontinuing or limiting the use of HDPE pipe. In 1997, the Director of School Planning and Construction issued a "departmental moratorium on any further use of HDPE for storm water piping until we can further evaluate its validity and longevity."

In 1998, the city of Knoxville, Tenn., indicated its exclusive use of concrete pipe within city right-of-ways. In 1997, the city of Gallatin, Tenn., advised that effective that year, corrugated polyethylene pipe would no longer be allowed for use in the street cross drains within the city of Gallatin. The Department of Public Works for the city of Pueblo has found significant failures in portions of HDPE storm sewers in subdivisions and will no longer allow HDPE to be placed in any of the city's public right-of-ways.

The state of Georgia requires a minimum of 25% of a pipe system to be mandrel-tested and any pipe over 5% deflection be removed and replaced. The state of Kentucky has reduced the condition of payment by up to 50% where inferior installation causes pipe to deflect beyond the 5% deflection limit. The state of Wisconsin requires a minimum of 10% of the system be mandrel-tested and any pipe over 5% deflection be removed and either reinstalled if not damaged or replaced at no cost. The state of Illinois requires mandrel testing of a piping system after 30 days of installation with pipe limited to 5% deflection. The state of Nevada does not allow pipe to exceed 5% vertical deflection after 30 days of installation and does not allow re-rounding of the pipe that does not meet the test.

The Kentucky Transportation Cabinet (KTC) formed a task force in May 2005 to evaluate current specification and use of HDPE pipe on future KTC projects based on performance inspections carried out in 2002 and July 2005. The results were published in a report entitled "Evaluation of HDPE Pipe Performance on Kentucky DOT Construction Projects." The results of the report note significant change in deflection since testing at completion. Most deflection was greater than 10%, and it was evident that several pipes continued to deflect after installation. The report also observed radial cracking, invert and crown flattening, racking and sagging. It was evident that radial cracking had occurred after installation. Additional video-laser testing was recommended for long-term performance analysis, and KTC has since revised sections of its specifications based on the results found in these reports.

A November 2003 Transportation Research Board paper, "The Economics of Culvert Failures," by Joseph Perrin and Chintan Jhaveri of the University of Utah, studied culvert failures in North America. Perrin and Jhaveri surveyed 57 agencies. Of the 25 that responded, only four stated that the agency performs a least-cost analysis for pipe material selection. Different agencies assumed a different life cycle for each material. The life cycle for HDPE pipe varied from 30 to 100 years. However, Perrin and Jhaveri concluded, "The reality is that pipes are not being replaced as they approach their expected service life."

Know the difference

Given the differences between RCP and corrugated HDPE pipe, it is essential that the engineer understands that the design of the two piping systems is vastly different. If the engineer does not fully recognize these differences and designs an HDPE system under the same conditions as a RCP system, there is a high probability that the system may not perform as intended or may ultimately fail.

The engineer must take into account these differences when designing a pipe system using corrugated HDPE pipe. Failing to take these differences into account when designing and specifying products places the engineer at risk. Even if ultimately settled, engineers suffer great loss in the course of litigation—to their professional reputations, as well as to their pocketbooks.

Engineers have a sworn duty to protect the health, safety and welfare of the public. Engineers must remember this duty when designing, specifying, requiring and enforcing. Failure to heed this duty may result in an engineer being the responsible party with all the associated risk, liability and consequences.

Author's Note: Some information in this article was taken from the PPI and ACPA websites.

Dr. Galloway is CEO of the Nielsen-Wurster Group. The American Concrete Pipe Association contracted with The Nielsen-Wurster Group to perform independent research comparing RCP and HDPE pipe. Galloway was one of several team members who were assigned at Nielsen-Wurster to perform that independent research. This paper reflects Galloway's own opinions, as a result of her participation in that research. As a matter of accommodation, Galloway would be delighted to review contradictory assertions advanced by others and if appropriate adjust her conclusions.

