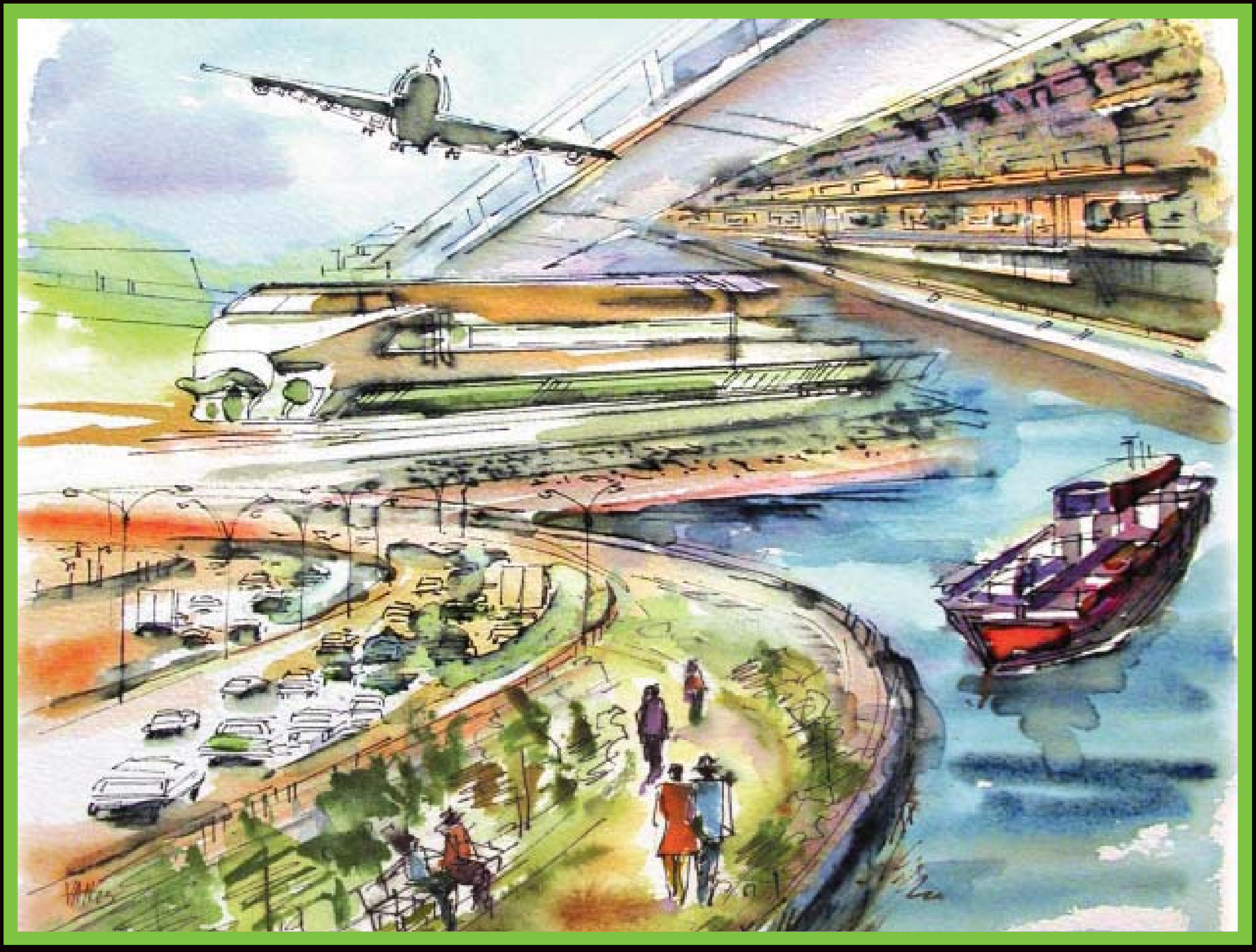
Sand Embedment of Corrugated Polyethylene Pipe



Presented at the National Transportation Research Board Annual Meeting, 2004

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Abstract

Installation of pipe and specifically corrugated high density polyethylene (HDPE) pipe has historically been accomplished with the use of crushed granular materials, such as number 57 stone or a well graded crusher run material. This material is believed to be the ideal bedding and backfill material for pipe because it has a uniform quality and requires very little compaction or installation effort to obtain a relatively high bearing pressure and proctor density. This fact explains why the use of this material is so widely used for roadway bed and foundations. The universal, blanked acceptance of this material over the years has led to a myopic view of installation of corrugated polyethylene pipe. This "ideal" material may truly be the best material for roadways but not necessarily flexible pipe. There is a material, which conforms to the wall curves of a corrugated polyethylene pipe, flows around the pipe into lower haunch zones and requires little compaction effort. This ideal bedding and embedment material for corrugated HDPE pipe is sand. This paper will provide the necessary research documentation and correlated field performance data to substantiate proposed recommendations installation details for corrugated polyethylene pipe with sand as its principle embedment material.

Introduction

Sand is the most widely available construction material in the world. It has been used since the dawn of time in the building of the great ancient civilizations of the Egypt, Greece and Rome. Uniform bearing has always been the principle requirement for structural foundation and no material is more accommodating than sand. It is literally impossible to obtain uniform support on hard rock material without the use of a material, which moves or repositions itself to create a constant pressure along a structures entire base. Failure to achieve this ideal structure bedding results in point loads and high stress areas. Pipe require the same basic uniform bedding as pyramids, temples and coliseums of old, except they must be maintained over miles in comparison to a mere acre.

Sand has a wide range of classifications. AASHTO, which under M 145, "Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes," has two main standard soil classifications identified as granular materials and silty-clay materials, defines sands in seven granular material subcategories from A-1 through A-3 materials. In all cases, however, these classifications rate sand from excellent to good for subgrade and embedment applications.

The ASTM installation specifications for thermoplastic pipe identify sand in Classes I through III. Unlike the AASHTO classifications, ASTM permits more clay and silty soils in their lower Class III materials. The AASHTO requirements, for example, are more course than ASTM, allowing only 35 percent of the material to pass the No. 200 sieve versus an ASTM limit as high as 50 percent. This material, however, is still recommended for use in pipe installations as long as the moisture content and compaction densities are properly controlled. Many of the corrugated HDPE pipe research studies, which will be examined in this paper, utilized this material and experienced very good field performance.

The following research studies and field investigations provide documentation that substantiates the good performance of sand for bedding and backfilling of corrugated HDPE pipe. These studies and field installations do not represent all the work and documentation on sand embedment of pipe, but do present some of the more recent work. In the limit forum, afforded here, they are summarized in a concise format to present the benefits of this material in pipeline design and to propose an economical and practical alternative to crushed angular rock for pipe installations.

Research Studies

The discussion of research studies on corrugated HDPE pipe in this paper will concentrate on the most recently completed studies, since there is an increasing awareness of the benefits of sand embedment in these publications. All of these studies, ironically, did not intend to address the benefits of sand embedment, but in most cases, to illustrate the benefits of a Class I crushed granular material over a Class III silty-sand material. A number of the studies were also initiated to study the stability of pipe wall profiles and/or maximum permissible depth of fill. The benefits of the sand embedment in these studies must, therefore, be selectively gleamed from the data rather than the conclusions, which predominately address the original scope of the project.

The basic design of corrugated HDPE pipe is not and will not be altered by any of these research studies, but rather the overlooked benefits of sand will be more clearly illustrated. The basic soil-structure interaction design methodologies developed by Spangler (1941), Watkins-Spangler (1958), and Burns-Richard (1964) are still pertinent and valid. The relationship of soils and soil modulus as reported by Howard, Duncan and Selig are the basis of the distinctions between sand and crushed stone, silts and clay used in this paper. These design procedures and soil parameters along with soil-structure interaction finite element models, such as CANDE, have been used in many of the studies illustrated here and may also be used independently to substantiate the results presented.

Purdue Testing

A field research study, "Bearing Capacity of 42-inch (1050-mm) Polyethylene Pipe," was conducted at Purdue University in 2001 to assess the performance characteristics of 42-inch corrugated HDPE pipe under simulated field conditions. Three-test pipe were installed and monitored in shallow unpaved parallel trenches under AASHTO HS20 live loads. The installations were classified as cells with unique bedding and backfill conditions.

Cells 1 and 2 were backfilled with gravel and overtopped with clay, designated as Class IA and Class V materials in ASTM D 2321, respectively. Cell 3 was backfilled with uniform silty-sand designated as Class III soil by ASTM D 2321, "Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity Flow Applications." All select material was placed in lifts and compacted to 90 percent standard proctor density. This select material was placed to the top of the pipe, with the remaining cover of approximately two feet in cells 1 and 2 being of very lightly compacted clay material. Cell 3 was completely backfilled with Class III silty-sand.

Upon completion of backfill, a fully loaded dump truck, equating to an AASHTO HS20 load, was placed on top of the pipe and deformation measurements taken. This process was repeated one month after installation to determine the effects of backfill consolidation on performance. Radial deformations of the pipe were taken before and after backfilling and during the truck loading.

The average strains in the crown and springline during the initial tests were 28 and 21 percent less, respectively, in the silty-sand cell 3 installation in comparison to the values obtained in cells 1 and 2 gravel installations. These results, one month later, were found to improved to 51 and 39 percent, respectively. The smaller deformations and larger differences in strains between the first and second tests can be attributed, in part, to the densification of the backfill material over time and the "self-compacting" nature of sand under loading in wet and dry cycles.

In general, the deformations in cell 3 were less than those in either cell 1 or cell 2. The researchers believe this improved performance is attributed to the sand backfill, which had a higher stiffness in comparison to the other backfills used. The field test results were also substantiated and reproduced by the researchers using the finite element model, ABAQUS.

Utah State Testing

Utah State University has done a significant amount of research work on the performance of buried structures. Most of their recent activities have centered on the performance of HDPE pipe under deep burial installations. Their work in this regard is very significant and pertinent to the review of the performance of sand embedment specifically since the vast majority of their pipe testing utilizes Class III silty-sand backfill.

The most recent Utah State University study, "Structural Performance of 42-inch (1050-mm) Corrugated Smooth Interior HDPE Pipe," was initiated in 2000 to determine the integrity of the 42-inch corrugated wall profile in bending and compression. Tests were performed on this pipe in the Utah State University large soil cell to determine the structural performance characteristics as a function of cover depth. Of most important to this paper's assessment of the performance of sand embedment are the independent variables of soil type, soil density and vertical soil load used in the testing.

The basic soil type used in the testing was a silty-sand, Class III ASTM D 2321 designation or AASHTO M 145 A-4 or A-5 silty soil. In the researcher's assessment this represented a worst-case test.

Three tests were conducted. All utilized 42-inch corrugate wall HDPE pipe in silty-sand embedment. The embedment compaction was the principal variable for the testing. The compaction levels of 75 percent, 85 percent and 95 percent standard proctor densities were utilized for Test 1, Test 2 and Test 3, respectively.

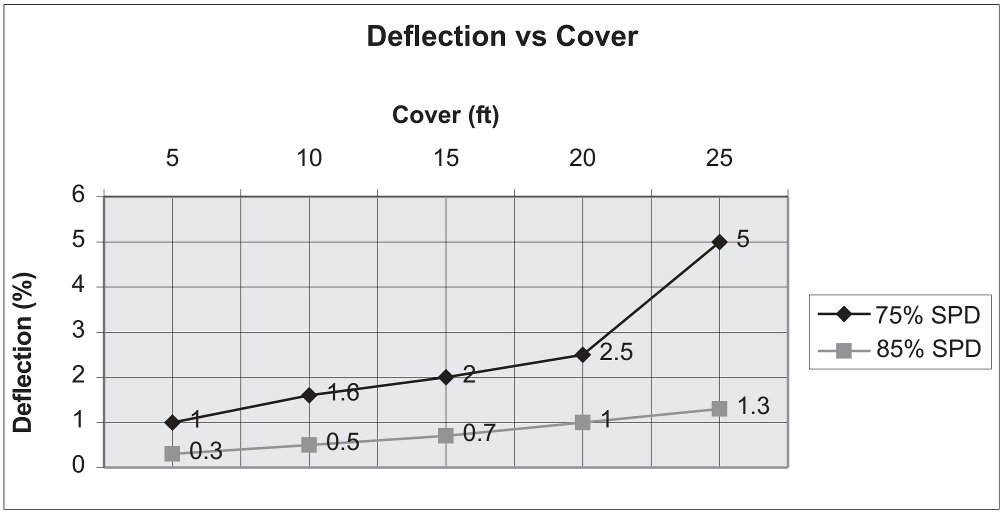


Figure 1: Comparison of Deflection Values for 75% and 85% SPD Material

The results for the Test 3 pipe installed in the 95 percent standard proctor density soil was, as expected, superior to the other two installations. The relative difference, however, in the more shallow installations, those defined here as 20-feet and under, was less significant (Figure 1). At 20 feet of fill the relative vertical deflections were approximately 2.5%, 1% and 0.25% for Test 1, Test 2 and Test 3 installations, respectively. This relatively close proximity of deflection values at a significant range of compaction levels indicates, at least under low to moderate fill heights, the level of compaction for a Class III silty-sand has a relatively minor impact on pipe performance. This gap, however, increased dramatically at fill heights greater than 20-feet.

Ohio University Testing

One of the more significant pipe research studies recently conducted was the 2002 Ohio University Study, "Field Verification of Structural Performance of Thermoplastic Pipe Under Deep Backfill Conditions." This study reported on the performance of thermoplastic pipe (12 HDPE and 6 PVC under relatively deep soil cover, 20 to 40-feet depth. The pipe ranged from 30-inch to 60-inch in diameter and the test samples represented product from most of the major pipe manufacturers. The testing involved two types of backfill, three relative compaction levels and varying bedding thickness to study the effects of these installation parameters on pipe performance.

Five of the installations were of HDPE pipe in sand embedment as illustrated in Table XX. The sand utilized in the testing met ODOT (Ohio Department of Transportation) 1997 Item 603.02 specifications for pipe and bedding backfill identified as Granular Material, Type 2. The ODOT Type 2 sand allows a very course gradation for sand, but the material used in the testing was in a relatively narrow band with 100%, 44% and 2% passing the No. 4, No. 40 and No. 200 sieve, respectively.

The maximum vertical deflection for these installations under 20 to 40 feet of fill was 3.5 percent (Table 1). These values correspond very closely to those previously reported in the Utah State University study.

Pipe Diameter (inches)	ISPD (%)	Filll Depth (feet)	Deflection (%)	
			Vertical	Horizontal
30	88.1	20	3.5	2.5
30	95.6	20	0.9	.06
30	95.6	40	3.3	.75
42	91.6	20	2.1	.24
42	95	40	2.4	.68

Table 1: Maximum Deflection Values for Deep Fill Installations

The consistent performance of the sand installations under these relatively deep burials compared very favorably to the crushed limestone backfill used for the other thermoplastic installations. The researchers commented that it appeared the sandy soil was nearly as good as the crushed limestone material for thermoplastic pipe structural fill. They attributed part of this performance to the small particle size of the sand that allowed it to be densified more easily against the corrugated pipe wall surfaces.

The sand installations also obtained additional benefits in loading and soil-structure interaction than the limestone installations. The deflection lag factor was larger in the crushed limestone than in the sandy backfill soil. This effect may indicate HDPE pipe in sand backfill achieves a higher degree of positive arching, similar to general observations noted between HDPE and PVC pipe. As a minimum, the data indicates dense sand was just as effective as dense limestone in relieving the vertical load acting over HDPE pipe.

The HDPE pipe in the sandy backfill conditions also experienced larger circumferential shortening than those in limestone backfill. Once again, similar observations were made between PVC and HDPE pipe in general. The deflection ratio ($\Delta V/\Delta H$) was larger in the sandy backfill soil then in the crushed limestone soil. All these factors indicate, the load on an HDPE pipe in a sand backfill will actually have a long-term reduction in loading greater than HDPE or PVC pipe installed in more traditional stone or crushed rock backfill.

The researchers also observed HDPE pipe in sand backfill experienced smaller vertical and lateral pressures at the crown and springline, respectively, with higher initial relative compactions. This condition was not true when similar pipe was installed in crushed limestone. The researchers believe this difference was due to the fact that the compaction of the course backfill material left a relatively loose zone against the corrugated surface of the HDPE pipe regardless of the intended relative compaction. The level of compaction was, therefore, not as significant to the performance of the corrugated HDPE pipe as was the selection of the type of backfill material.

Field Evaluations

The field evaluations presented here provide a comparison that substantiates the research results between crushed limestone and sand. An example is also presented on the use of native sand material in lieu of imported granular material. It would be unfeasible to present a discussion of all HDPE pipe sand embedment installations or even a list of such projects in the confines of a technical paper. These two examples are only presented to document the points to be made in the conclusion of this paper. To ensure these installations also represented typical construction techniques, no supervision or special guidelines were provided to the contractor.

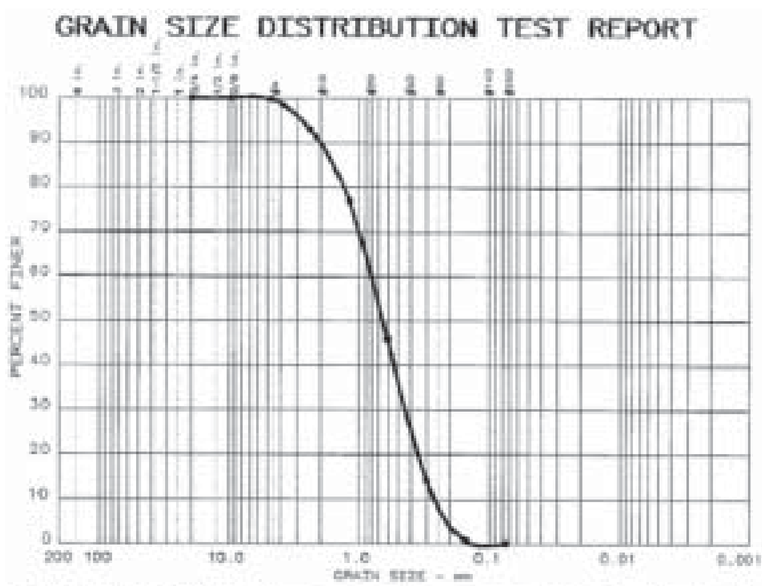
For further documentation of the growing acceptance of sand embedment over crushed stone backfill, one can review local specifications and standards. In some, especially in localities where sand is plentiful and stone or rock is a premium, native and quarry sands are the dominant pipe embedment material.

Lift Station G
City of Moberly, Missouri

Four separate lines of 60-inch corrugated HDPE pipe were installed in April 2003 utilizing either 0.75-inch (minus) crushed limestone or course graded sand. The installations were 200-foot parallel storage pipe for a city lift station under 4.9 to 5.9-feet of fill and for all practical purposes had identical site conditions. All the material placed for each section of pipe was monolithic, the bedding and embedment material were identical for each installation. Compaction density requirements were in accordance with City specifications.

Pipe 1 and 2 were embedded in crushed limestone with Pipe 3 and 4 utilizing sand. The sand contained only 0.1% of silt or clay material with a generally course gradation as indicated in the sieve analysis (Figure 2). Twenty measurements were taken in each pipe run at 4-feet on either side of a joint on the 20-foot lengths of pipe. These field measurements were taken in April 2003, approximately 60 days after the completion of the installation. The average deflections in Pipe 1, 2, 3 and 4 were 1.1%, 1.0%, 0.4% and 0.8%, respectively. The maximum deflection observed in each line was 4.8%, 3.3%, 2.0% and 3.3%, respectively.

These field performance conditions closely mirrored those obtained in the Ohio University study. The deflections measured in these sand installations were equivalent or superior to those obtained with crushed limestone installations, and in all cases, less than 5 percent. No special installation techniques or guidelines were utilized in installing these pipe (Figure 3). Since the insitu-soil was stable, minimum trench width requirements (Pipe O.D. plus 16-inches) per ASTM D 2321were utilized for all four of these installations.



Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
1	0.0	0.3	99.6	0.1	

Figure 2: Sieve Analysis – Moberly, Missouri
Solar Testing Laboratories

Figure 3: Sieve Analysis – Moberly, Missouri
Solar Testing Laboratories

To prevent any infiltration of material into the pipeline or exfiltration of the storage water, gasketed pipe were supplied for all installations on this project. All lines were consequently hydrostatically tested to ensure joint integrity.

Blaine, Minnesota

Blaine, Minnesota is located in a glacial till area, where the native soil is predominately sand. The City of Blaine's specifications, therefore, allow for the use of this native material for bedding and backfill of storm drainage pipe. Soil samples of this material, as illustrated in the sieve analysis, indicated relatively consistent, uniform graded material with occasional clay particles (<3%). Excluding the clay particles, 100 percent of the sand passed the No. 50 sieve (Figure 4).

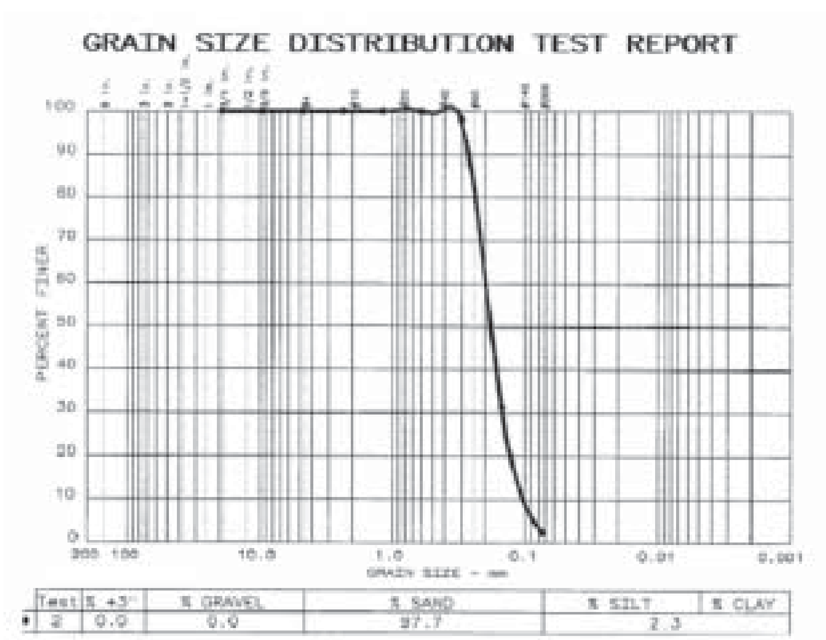


Figure 4: Sieve Analysis of Native Material – Blaine, Minnesota
Solar Testing Laboratories

Three random projects were inspected in Blaine to assess the long-term performance characteristics with the use of this native sand material (Figure 5). These installations were installed with dumped sand and no recorded compaction. Two residential subdivisions, Knoll Creek Estates (105th Avenue NE) and Pleasure Creek (Jackson Street NE), that have been in place for over 2-years were first examined to determine if unsupervised private contractor installation techniques adversely affected the performance of these installations. Both installations had deflections near the original nominal pipe diameters with little or no deflection. The Jackson Street project, however, did contain a localized longitudinal sag in the pipeline, which could have been a result of either poor line and grade control during the initial installation or possible infiltration of backfill materials into the line.

Figure 5: Typical Insitu-Soil Conditions in Blaine, MN

A pipe under a minor collector street was also inspected as a comparison of municipal construction techniques and performance relative to private development. This pipe had no post construction irregularities and had deflections well under 5 percent throughout the line.

Stiffness Versus Density

One of the other unique benefits of sand over crushed stone, and silty or clay materials are its consistency in stiffness regardless of compaction density. A study, "MnDOT Overload Field Tests of Standard and SIDD RCP Installations," that was conducted for the Minnesota Department of Transportation investigated the performance of sand and clay in typical reinforced concrete pipe installations. The key conclusions of this study are independent of pipe material and provide further documentation of benefits of sand as installation insensitive material. The researchers noted soil stiffness plays a more significant role than soil density in the performance of pipe. The level of compaction of sand had little effect on the overall performance of pipe. The lack of sensitivity with regard to stiffness and density of this material compared to compaction efforts makes it the ideal pipe bedding material. They believe their findings support the use of sand over any other material if consistent, high quality bedding is needed.

The Utah State University testing supports these findings. A review of the compaction densities for the silty-sand soil used in their study show relatively minor differences in deflection values for 75%, 85% and 95% standard proctor density at moderate depths of fill. The Blaine, Minnesota installations also indicate that consistent results are obtained with dumped insitu-soil sands regardless of the compaction, which certainly varied on multiple unsupervised projects.

According to the MnDOT study, soil stiffness is the key soil parameter for insuring adequate structural performance of pipe. Historically, specifiers have concentrated on obtaining high soil densities for embedment material, but this study disputed these commonly held design principles. The study also noted the sensitivity of clay soils with regard to compaction, stiffness and density bridged the full spectrum form excellent to poor. Sand, on the other hand, performed well for all installations regardless of soil density. Dumped sands had similar performance to those compacted and had consistent relative dry density values. Sand should, therefore, not be classified with the same design parameters and controls used for clay or other materials, which must have a compaction effort applied to them to obtain high soil stiffness values.

Economic Viability of Sand

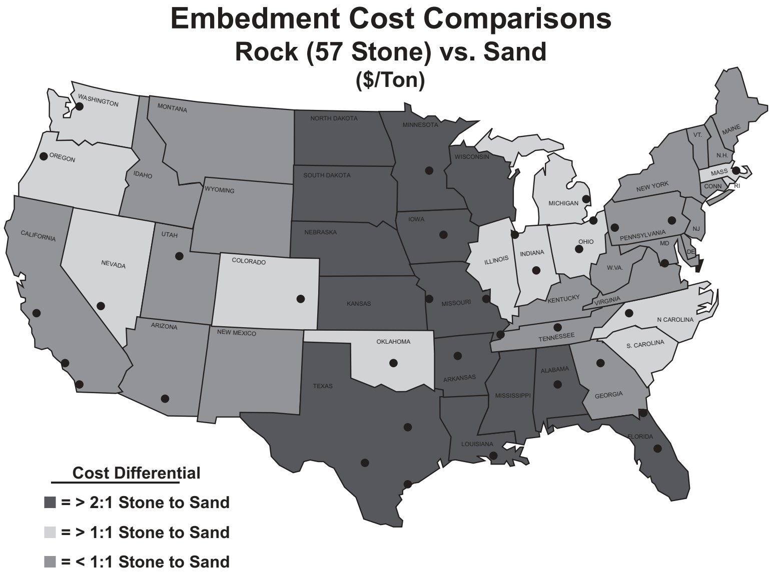


Figure 6: Geographical Comparison of Sand to Stone Costs

One of the other unique benefits of sand is its wide availability and relatively low cost. A detailed cost analysis on aggregated costs for No. 57 stone versus quarry sand was conducted utilizing multiple quarries in each major metropolitan area in the United States as illustrated in Figure 6. The results indicate sand is less than 50 percent of the cost of stone in mid-section of the Country. In some of these locations, stone was five times the cost of sand. The only areas where stone costs were equivalent to sand were states with more mountainous terrains; otherwise, substantial cost savings would be available in the majority of the Country.

Summary

The main reasons for embedding corrugated HDPE pipe in sand are threefold. First, as indicated by the research and field studies, sand performs as well as crushed stone, and for HDPE pipe with external corrugations, superior to open graded stone. Second, due to the self-compacting nature of sand, little, if any, compaction effort is necessary to obtain a high stiffness sand embedment. Finally, sand is the most cost effective and abundant structural embedment material available throughout the majority of the United States.

The studies conducted at Purdue University and Ohio University indicate that sand performs better than crushed limestone or gravel. Corrugated HDPE pipe installed in sand had lower strains and similar, if not smaller, vertical deflections. Both studies also indicate sand conforms better to the sinusoidal exterior corrugation pattern of the pipe. This characteristic of sand may provide reason for its better overall performance to the more traditional granular material. The uniform support provided around the entire corrugation creates a larger bearing surface for the bedding, haunch and sidefill reaction forces. Sand, therefore, may not be as beneficial to pipe with exterior smooth walls as they are with corrugated walls.

These results were further substantiated in the City of Moberly field evaluations for the sand and crushed limestone installations. Deflection measurements were similar for all installations regardless of the embedment material. So although crushed granular material is considered a superior structural foundation material, which it may well be, for corrugated HDPE pipe, its benefit is offset by sands ability to easily conform to the exterior wall geometry of pipe even under unsupervised contractor construction techniques.

The MnDOT study provided the most important insight, and thereby the most controversial: high soil stiffness values for sand are obtained regardless of compaction effort. The results of this study supported the good performance data obtained in the Ohio, Purdue and Utah studies and the Blaine field surveys, but for a different reason. Sand installations perform well regardless of compaction effort.

The use of sand for embedment of corrugated HDPE pipe does have some limitations. The sand must be a graded quarry material. Manufactured sands or uniform graded sands, such as beach sands, would not be a desirable embedment material. These materials do not obtain high stiffness values due to their uniform gradation, which does not allow for the interlocking of particles. Pipe installations, which utilize sand embedments, must also be watertight to prevent infiltration of the backfill material into the pipeline. The level of seal will vary somewhat depending on the site conditions, but the pipe, as a minimum, must have a rubber gasketed joint with at least a 2-psi pressure rating.

In conclusion, the use of sand embedment is not only viable option for corrugated HDPE pipe installation, but should be the recommended procedure in lieu of crushed stone. This material can be used immediately with the current ASTM and AASHTO standards and only requires the revision of local and state standards to permit its use as the preferred design option. Sand embedment may very well be the answer design engineers have been searching for to address the issue of installation sensitivity for pipelines.

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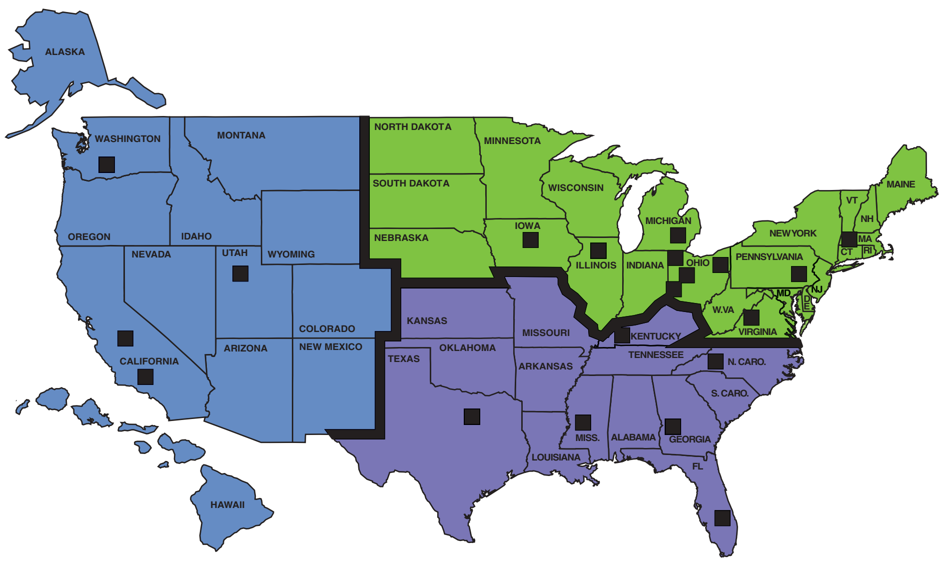

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