# Allowable Fill Heights for Corrugated Polyethylene Pipe 

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#### Abstract

Provided in this study are fill height tables and graphs that give the maximum allowable burial depth of regularly produced sizes of corrugated polyethylene pipe with diameters ranging up to 30 in . The employed design criteria satisfy the proposed American Association of State Highway and Transportation Officials specifications for service load design of plastic pipe including thrust stress, vertical deflection, flexural strain, and buckling. Both short-term and long-term polyethylene properties are used for the design evaluation, as well as the influence of soil type and compaction. Design solutions are determined with the aid of the CANDE computer program and compare favorably with laboratory test data. As a final result, knowing values for the inside and outside diameter along with the corrugated sectional area, an engineer may determine the maximum allowable burial depth for a 50 -year design life by directly reading from the tables and graphs that are presented as a function of soil type and compaction. In addition, design guidelines are provided to interpolate the increase in allowable burial depths for design periods less than fifty years.


Corrugated pipe composed of high density polyethylene has become an economically attractive alternative to corrugated metal, clay, and reinforced concrete pipe in small-diameter culvert applications. Prior to this work, however, a rational set of tables and guidelines to determine the maximum allowable burial depth of corrugated polyethylene pipes has not been published in the open literature. Such fundamental information is required for a variety of applications, such as culverts under deep highway embankments.

Herein lies the objective of this paper. Using proven principles and techniques of soil-structure interaction analyses, tables are developed that give the maximum allowable fill height for corrugated polyethylene pipe based on structural considerations that take into account pipe size, corrugation geometry, backfill soil quality, and design life.
Pipe sizes (i.e., the inside diameters) considered in this study are $4,6,8,10,12,15,18,24$, and 30 in . For each pipe size, the corrugated sectional area (i.e., area resisting hoop compression per unit length of pipe) is treated as the major design variable. Coupled with each pair of values for pipe size and sectional area are polyethylene property variations for short- and long-term behavior. Also considered are soil property variations, ranging from fair to good quality dependent on soil type and level of compaction.

All combinations of these variables constitute the input data to the soil-structure analysis program, CANDE (1). Output is the allowable fill height as a function of input in conformance

[^0]with the American Association of State Highway and Transportation Officials (AASHTO) design criteria and specifications (2). Details of the design input variables, design methodology, and final results are presented in sequential order.

The following limitations and restrictions should be kept in mind. Results are only applicable to high-fill installations, that is, live loads are negligible. The soil envelope surrounding the pipe is assumed homogeneous and properly compacted; this excludes the use of hard beddings or stiff inclusions, or both, as well as loose or soft backfill materials within two diameters of the pipe circumference. In spite of these restrictions, the overall design approach is very conservative so that the allowable fill heights may be used with a great deal of confidence.

## CORRUGATED PLASTIC PIPE PROPERTIES

For structural analysis, the robustness of a corrugated pipe can be assessed by the hoop stiffness, which is proportional to the corrugated section area, and by the flexural (ovaling) stiffness, which is proportional to the corrugation moment of inertia. As will be shown later, the corrugated section area is the key section property that controls the allowable burial depth because thrust stress (hoop stress) is almost always the controlling design criterion. Accordingly, the moment of inertia does not influence the allowable burial depth as long as its value is greater than a certain minimum value that precludes deflection, flexural strain, or buckling from controlling the design.

Unlike the corrugated metal pipe industry, the manufacturers of corrugated plastic pipe do not employ a standardized set of corrugated shapes for each pipe diameter. Rather, a typical plastic pipe manufacturer makes only one corrugation size per pipe size. However, the corrugated shape made by one manufacturer and that of another may differ markedly in material thickness, shape, and height of the corrugation. The only geometric pipe property that is reasonably well standardized is the inside diameter, also called the pipe size.

A special study on the corrugated section properties was obtained from five of the largest plastic pipe manufacturers and is described as follows.

## A STUDY OF CORRUGATED SECTION PROPERTIES

## Manufacturers' Data

Shown in Figure 1 is a typical corrugated cross-section and listed in Table 1 are corrugated section properties reported


FIGURE 1 Corrugated sections, with $A$ and $h$ constant.
by five of the largest plastic pipe manufacturers from a letter survey. The variation in section properties within each pipe size is readily apparent. This expected scatter of values, however, is amplified by computational errors in computing or reporting the section properties. Thus, a reliable method of determining corrugated section properties needs to be developed before a workable design methodology can be established. These issues are addressed for the corrugated section area, moment of inertia, and corrugation height in the following.

## Section Area

A simple, yet reliable, method of determining the section area was suggested by William Altermatt of Hancor, Inc. The method entails weighing a pipe of length $L$, and measuring the inside and outside diameters. Knowing the density of polyethylene, the section area is then given by
$A=2 W /[L d \pi(I D+O D)]$
where

$$
\begin{aligned}
A & =\text { cross-sectional area }\left(\text { in. }{ }^{2} / \mathrm{in} .\right), \\
W & =\text { weight of pipe }(\mathrm{lb}), \\
d & =\text { polyethylene density }\left(\mathrm{lb} / \mathrm{in} .{ }^{3}\right), \\
& \text { high density polyethylene }=0.0344 \mathrm{lb} / \mathrm{in} .{ }^{3}, \\
\mathrm{ID}, \mathrm{OD} & =\text { inside and outside diameters (in.), and } \\
\pi & =3.14 .
\end{aligned}
$$

Equation 1 is derived by equating the measured weight $W$ to the product of the pipe's solid volume times the density $d$. The solid volume is given exactly by the product $2 \pi A L R$, where $R$ is the pipe's radius to the geometric centroid of the corrugated section. In Equation 1, it is assumed that the cor-
rugation is symmetric so that $R=(\mathrm{ID}+\mathrm{OD}) / 4$ (i.e., $R$ is at mid-height of corrugation). For nonsymmetric corrugations, Equation 1 introduces a small error, but certainly less than 5 percent.

Following a second letter survey, the five manufacturers recomputed the section areas in accordance with Equation 1, and the results are shown in the last column of Table 1. It may be observed that these values show more uniformity than the original set, and it is believed that the variations that do exist in the revised properties reflect real differences between pipe products.

## Moment of Inertia

As already stated, the moment of inertia does not influence the allowable burial depth because thrust stress usually controls the design. Thus, for design purposes, a relationship is sought that serves as a lower bound for the "actual" moment of inertia used in manufactured products. If it is found that the lower bound is adequate (i.e., thrust is still the weak link), then it can be assumed that the actual moment of inertia is adequate.
To establish a lower bound, consider the following expression for the moment of inertia, I:
$I=A h^{2} / z$
where

$$
\begin{aligned}
A & =\text { corrugation sectional area, } \\
h & =\text { height of corrugation }=(\mathrm{ID}-\mathrm{OD}) / 2, \text { and } \\
z & =\text { a constant, dependent on corrugation form. }
\end{aligned}
$$

Given that $A$ is known (e.g., by Equation 1), and because $h$ is easily measured, then the value of $I$ in Equation 2 depends on the shape parameter $z$, that is, how the material is distributed about the centroid. Nów the largest possible value for $I$ would be achieved by splitting the net area into two parts separated by the corrugation height $h$, as shown in Figure $1(b)$. Although this is not physically possible because it does not leave any web material to connect the two parts, it is an upper bound for $I$ from which the parameter $z$ is easily deduced: $z=4$. If, on the other hand, all the material area is distributed to web-like connectors, as shown in Figure 1(c), then a theoretical lower bound on $I$ is found from which the parameter $z$ is again easily determined: $z=12$.

Using these theoretical upper and lower bounds, the consistency of manufacturers' data in Table 1 can be checked and a practical lower bound established. From Equation $2 z=$ $A h h / I$ can be computed, where $I, A$, and $h$ are taken directly from Table $1[A$ is the revised area, and $h=(\mathrm{OD}-\mathrm{ID}) /$ 2]. These values of $z$ are shown in Figure 2 as a range of five values for each pipe size. Note that some of the plotted $z$ values are less than 4 , implying that the associated values for $I$ are clearly too high, exceeding the theoretical upper bound. Note that the $z$ values are greater than 12, implying none of the reported values for $I$ are clearly too low. As shown in Figure 2(c), the line $z=10$ provides a reasonable lower bound estimate for design. Said another way, all reported values of $I$ are greater than the value of $I$ given by Equation 2 with $z=10$.

TABLE 1 MANUFACTURED SECTION PROPERTIES

| NOMINAL DIAMETER in | MANUFACTURER* | INSIDE DIA. in | OUTSIDE DIA. in | $\begin{gathered} \text { AREA } \\ \text { (ORIGINAL) } \\ \mathrm{in}^{2} / \mathrm{in} \end{gathered}$ | $\begin{aligned} & \text { MOMENT } \\ & \text { INERTIA } \\ & \text { in } 4 / \mathrm{in} \end{aligned}$ | $\begin{gathered} \text { AREA } \\ \text { (REVISED) } \\ \text { in }^{2} / \mathrm{in} \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 4 | A | 4.02 | 4.72 | 0.0533 | 0.001103 | 0.056 |
|  | 0 | 3.94 | 4.86 | 0.186 | 0.00211 | 0.060 |
|  | P | 4.10 | 4.70 | 0.0564 | 0.000834 | 0.053 |
|  | U | 4.06 | 4.65 | 0.0644 | 0.000966 | -. |
|  | H | - | -- | -- | , | 0.053 |
| 6 | A | 6.00 | 6.92 | 0.07.17 | 0.00343 | 0.086 |
|  | 0 | 5.91 | 6.89 | 0.2234 | 0.00795 | 0.081 |
|  | P | 5.94 | 6.87 | 0.1150 | 0.00389 | 0.075 |
|  | U | 6.06 | 6.75 | 0.0873 | 0.00201 | - |
|  | H | - | - | - | , | 0.060 |
| 8 | A | 8.12 | 9.50 | 0.0917 | 0.010 | 0.102 |
|  | 0 | 7.87 | 9.25 | 0.234 | 0.0151 | 0.102 |
|  | P | 7.79 | 9.47 | 0.112 | 0.00791 | 0.092 |
|  | U | 8.16 | 9.63 | 0.111 | 0.00709 | - |
|  | H | - | - | -- | , | 0.081 |
| 10 | A | 10.11 | 11.90 | 0.125 | 0.019 | 0.128 |
|  | 0 | 9.84 | 11.81 | 0.222 | 0.0364 | 0.144 |
|  | P | 9.98 | 11.71 | 0.145 | 0.0146 | 0.120 |
|  | U | 10.20 | 11.83 | 0.0886 | 0.0171 | - |
|  | H | , | - | -- | , | 0.114 |
| 12 | A | 12.10 | 14.80 | 0.125 | 0.034 | 0.166 |
|  | 0 | 11.81 | 13.98 | 0.235 | 0.046 | 0.161 |
|  | P | 11.77 | 14.16 | 0.292 | 0.0505 | 0.173 |
|  | U | 12.18 | 14.42 | 0.117 | 0.0283 | -- |
|  | H | 11.85 | 14.03 | 0.168 | 0.0260 | 0.156 |
| 15 | A | 15.05 | 18.80 | 0.178 | 0.070 | 0.193 |
|  | 0 | 15.75 | 18.50 | 0.250 | 0.0612 | 0.212 |
|  | P | 14.35 | 18.70 | 0.227 | 0.0917 | 0.196 |
|  | U | 15.00 | 18.44 | 0.396 | 0.153 | -- |
|  | H | 14.81 | 17.74 | 0.224 | 0.059 | 0.184 |
| 18 | A | 17.86 | 21.41 | 0.230 | 0.090 | 0.231 |
|  | 0 | 17.72 | 20.67 | 0.276 | 0.0867 | 0.238 |
|  | P | -- | -- | - | -- | 0.224 |
|  | U | 18.10 | 21.28 | 0.296 | 0.111 | -- |
|  | H | 18.20 | 21.51 | 0.214 | 0.077 | 0.227 |
| 24 | A | 23.86 | 28.16 |  | 0.200 | 0.336 |
|  | 0 | 23.62 | 27.95 | 0.297 | 0.1696 | 0.332 |
|  | P | -- | -- | - | - | 0.289 |
|  | U | 24.375 | 27.875 | 0.322 | 0.159 | . |
|  | H | 24.20 | 28.40 | 0.277 | 0.155 | 0.299 |
| 30 | A | - | - | -- | - |  |
|  | 0 | -- | -- | - | - | -- |
|  | P | $\cdots$ | $\stackrel{-}{-}$ | $\cdots$ | - | - |
|  | U | 30.00 | 34.55 | 0.356 | 0.244 | - |
|  | H | - | - | -* | $\cdots$ | - |
|  |  |  |  |  |  |  |

*MANUFACTURERS
$A=A D S$
$O=B i g O$
$\mathbf{U}=$ United Extrusions
P = Plastic Service, Inc.
H = Hancor

## Corrugation Depth

Although the corrugation depth is easily measured, a design relationship is sought that will give a lower bound estimate for $h$ as a fraction of pipe size. Shown in Figure 3 are the data points, ID $/ h$ versus ID, taken from Table 1. Here it is observed that II) $/ h=14$ provides the desired relationship, that is,
in all cases the corrugation height is greater than $1 / 14$ of the diameter.
To summarize, this study provides a simple method to accurately determine the section area $A$ using Equation 1 . Knowing $A$, a lower bound estimate for the moment of inertia is given by Equation 2 in which the corrugation height can be taken as $1 / 14$ of the inside diameter.


FIGURE 2 Consistency check on moments of inertia.

## Pipe Geometry

Based on this study, the "matrix" of corrugated section areas selected for the design study is listed in Table 2. That is, for each pipe diameter, three corrugated section areas are chosen and designated as low, medium, and high values so that the high and low values bracket the actual values reported by the manufacturers. For the sake of uniformity, the range between high and low values of sectional areas is kept constant at 0.1 in. ${ }^{2} / \mathrm{in}$.

Associated with each pipe size and sectional area in Table 2 , the design procedure conservatively assumes that the corresponding moment of inertia is given by Equation 2 and the corrugation height is given by Equation 1.

## Pipe Material

Polyethylene exhibits significant creep behavior under constant loading. Thus, the effective long-term modulus is considerably lower than the short-term modulus. Summarized in the following table is the AASHTO M294 specification.

| Time Period <br> (yrs) | Young's Modulus <br> (Ib/in. ${ }^{2}$ ) | Tensile Strength <br> (Ib/in. ${ }^{2}$ ) |
| :--- | :--- | :--- |
| Short term <br> $(0.05)$ | 110,000 | 3,000 |
| Long term <br> $(50.0)$ | 22,000 | 900 |

It can be seen from this table that the recommended modulus for the long term ( 50 years) is five times less than it is for the short term. Stiffness reductions of this order are typical for polyethylene, as shown, for example, in linear log (modulus) versus log (time) plots (3).

Strength behavior is not as well studied or understood as stiffness. The AASHTO specifications, as shown in this table, suggest that the long-term strength is reduced by a factor of 3.3 from the short-term strength, a seemingly rather large reduction. In any event, the properties in the table are adopted from this study with the firm belief that they are conservative values in keeping with the stated design philosophy.


FIGURE 3 Reported diameter-to-corrugation height ratios.

## DESIGN METHODOLOGY

## CANDE Program

CANDE (Culvert Analysis and Design) is a well-known and well-accepted finite element computer program developed especially for the structural design and analysis of buried conduits ( $1,4-6$ ). Both the pipe and the surrounding soil envelope are incorporated into an incremental, static plane strain formulation. The pipe is modeled with a connected sequence of beam-column elements, and the soil is modeled with continuum elements. For this study, CANDE was modified to automatically determine the allowable fill height, described subsequently. The fundamental analysis assumptions are small deformation theory, linear elastic polyethylene properties (short and long term), bonded pipe-soil interface, Level 2 solution method, and the Duncan soil model.

## Design Criteria

Listed in the following table are the four design criteria for polyethylene pipe, of which the measures of pipe distress are

TABLE 2 RANGE OF SECTION AREAS ANALYZED*

| Pipe ID <br> in. | Corrugation Area: in $2 / \mathrm{in}$ |  |  |
| :---: | :---: | :---: | :---: |
|  | low | medium | high |
| 4 | 0.04 | 0.09 | 0.14 |
| 6 | 0.05 | 0.10 | 0.15 |
| 8 | 0.06 | 0.11 | 0.16 |
| 10 | 0.08 | 0.13 | 0.18 |
| 12 | 0.10 | 0.15 | 0.20 |
| 15 | 0.15 | 0.20 | 0.25 |
| 18 | 0.20 | 0.25 | 0.30 |
| 24 | 0.25 | 0.30 | 0.35 |
| 30 | 0.30 | 0.35 | 0.40 |

thrust stress, relative deflection, flexural strain, and buckling pressure. These criteria satisfy the AASHTO requirements for service load design (2). In this study, the criteria are applied to both long- and short-term design life. These criteria are accepted here at face value, even though the thrust stress criterion is thought to be very conservative.

Distress Measure<br>Thrust stress<br>Flexural strain<br>Relative deflection (vertical)<br>Buckling pressure

Allowable Limit<br>$1 / 2$ yield stress<br>5.0 percent<br>7.5 percent<br>$1 / 2$ critical pressure<br>[Chelapati-Allgood<br>buckling theory (1)]

## Soil Model

All design cases are analyzed for two soil conditions generically called "fair" and "good" quality soil. Specifically these two cases were represented by the Duncan soil models for silty clayey sand at 85 percent compaction (fair $=\mathrm{SC} 85$ ) and silty clayey sand at 100 percent compaction (good = SC 100). The Duncan model parameters for these two soil conditions are listed in Table 3. More general interpretations for these two bracketing cases are given elsewhere in this paper, allowing the solutions to be interpolated over a range of soil types and conditions.

## Design Procedure

The design procedure is best described by summarizing the CANDE input and output. Table 2 contains 27 different input geometries composed of 9 pipe sizes with 3 sectional areas per pipe size. Each of these input geometries is analyzed four times, that is, all combinations of short- and long-term polyethylene properties listed in the in-text table in the Pipe Material section of this paper together with the two soil models representing fair and good soil quality. Overall, 108 design solutions were obtained with CANDE. Each design solution is obtained by sequentially placing layer after layer of soil above the pipe in 2- to 3-ft increments until one of the four design criteria is violated. At that point, the program determines what proportion of the last increment exactly satisfies the controlling design criterion, thereby determining the precise allowable fill height. Output consists of the allowable fill height, the controlling design criterion along with the status of the other criteria, and the complete set of structural responses at the allowable burial depth.

## RESULTS

## Comparative Studies

As a prelude to presenting the complete set of design solutions, it is instructive to compare how the four design criteria independently control the allowable fill height and, at the same time, compare predicted performance with experimental laboratory data from Utah State University (7). Computed allowable fill heights for an $18-\mathrm{in}$. corrugated plastic pipe with a sectional area of $0.22 \mathrm{in} .^{2} / \mathrm{in}$. used in the Utah State University study are shown in Figure 4. For each of the four design criteria, four different fill heights are shown representing the four combinations of two soil conditions and two polyethylene conditions. It is evident that the thrust stress criterion controls in all cases, however, less so for fair soil than for good soil. Superimposed on the figure is a data point for the deflection criterion from a simulated deep burial test in the Utah State University soil cell in which the soil was reported as a silty clayey sand compacted to 85 percent AASHTO T-99 (fair soil). A deflection reading of 7.5 percent was recorded at an over pressure of $4,700 \mathrm{lb} / \mathrm{ft}^{2}$, or 40 ft of equivalent fill height, which agrees remarkably well with the calculated fill height of 43 ft for the 7.5 percent deflection criterion for the case of fair soil and short-term loading. The Utah State University test did not include strain gauges so the thrust stress or flexural strain criterion could not be checked, however, Utah State University investigators observed the initiation of corrugation dimpling at $7,500 / \mathrm{ft}^{2}$ ( 63 ft of fill).

## Design Tables

The allowable fill heights for all 108 cases are listed in Table 4. The thrust stress criterion controlled in all cases except for four cases (marked with asterisks), in which the deflection criterion controlled marginally. On average for all cases, the deflection criterion would allow 25 percent more fill height, the flexural criterion would allow 30 percent more fill height, and the buckling criterion would allow 55 percent more fill height than the controlling thrust criterion. There is, however, substantial variation of individual cases from these average trends.

A graphic representation of Table 4 is shown in Figures 5, 6 , and 7. Here, the dramatic influence of soil quality on the allowable fill height is readily apparent, as is the effect of short-term versus long-term pipe properties. In addition to showing how deep given pipe geometry can be buried as a function of soil quality and design life, these figures also answer

TABLE 3 STANDARD HYPERBOLIC PARAMETERS (5)

| Soil | $\phi$ | $\mathrm{d} \phi$ | $C$ | K | n | Rf | Kb | m |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Type | (deg) | (deg) | (psf) | - | - | - | - | - |
| (SC-85) | 33.0 | 0.0 | 200. | 100. | 0.6 | 0.7 | 50.0 | 0.5 |
| (SC-100) | 33.0 | 0.0 | 500. | 400. | 0.6 | 0.7 | 200.0 | 0.5 |
|  |  |  |  |  |  |  |  |  |



FIGURE 4 Allowable fill height versus design criteria.
the inverse question: what sectional area is required to withstand a given burial depth?

## DESIGN GUIDELINES

The use of Table 4 and the associated Figures 5, 6, and 7, is straightforward as long as the design problem matches the prescribed conditions, that is, soil density is $120 \mathrm{lb} / \mathrm{ft}^{3}$, soil quality is either fair or good, and design life is long term or short term only. For more generality, the following interpolation schemes are provided to permit design solutions for variations in soil density, soil quality, and design life.

## Soil Density

The allowable fill height given in Table 4 or, equivalently, in Figures 5, 6, and 7, is based on a reference soil density, $S=$ $120 \mathrm{lb} / \mathrm{ft}^{3}$. Letting $S^{*}$ denote the actual soil density, then the corresponding fill height $H^{*}$ may be computed as,

$$
\begin{equation*}
H^{*}=\left(S / S^{*}\right) H \tag{3}
\end{equation*}
$$

TABLE 4 DESIGN TABLE FOR ALLOWABLE FILL HEIGHT

| PIPE PROPERTIES |  | ALLOWABLE FILL HEIGHTS |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| ID <br> in | Corrugation Area in $^{2} / \mathrm{in}$ | Good S <br> (ft) | ty Soil <br> L <br> (ft) | Fair Q S <br> (ft) | ality Soil L <br> (ft) |
| 4 | $\begin{aligned} & .04 \\ & .09 \\ & .14 \end{aligned}$ | $\begin{gathered} 45.0 \\ 87.3 \\ 125.2 \end{gathered}$ | $\begin{aligned} & 25.2 \\ & 41.4 \\ & 56.6 \end{aligned}$ | $\begin{aligned} & 31.5 \\ & 63.4^{*} \\ & 76.9^{*} \end{aligned}$ | $\begin{aligned} & 12.0 \\ & 23.7 \\ & 35.2 \end{aligned}$ |
| 6 | $\begin{aligned} & .05 \\ & .10 \\ & .15 \end{aligned}$ | 39.0 68.6 95.5 | $\begin{aligned} & 23.0 \\ & 34.3 \\ & 44.9 \end{aligned}$ | $\begin{aligned} & 26.3 \\ & 51.3 \\ & 65.7^{*} \end{aligned}$ | $\begin{aligned} & 10.3 \\ & 18.2 \\ & 26.0 \end{aligned}$ |
| 8 | $\begin{aligned} & .06 \\ & .11 \\ & .16 \end{aligned}$ | $\begin{aligned} & 35.6 \\ & 58.1 \\ & 79.1 \end{aligned}$ | $\begin{aligned} & 21.9 \\ & 30.6 \\ & 38.6 \end{aligned}$ | $\begin{aligned} & 23.6 \\ & 42.3 \\ & 58.8^{*} \end{aligned}$ | $\begin{array}{r} 9.6 \\ 15.2 \\ 21.3 \end{array}$ |
| 10 | $\begin{aligned} & .08 \\ & .13 \\ & .18 \end{aligned}$ | $\begin{aligned} & 37.3 \\ & 55.3 \\ & 72.4 \end{aligned}$ | $\begin{aligned} & 22.8 \\ & 29.7 \\ & 36.2 \end{aligned}$ | $\begin{aligned} & 25.0 \\ & 40.0 \\ & 54.8 \end{aligned}$ | $\begin{array}{r} 10.1 \\ -\quad 14.8 \\ 19.5 \end{array}$ |
| 12 | $\begin{aligned} & .10 \\ & .15 \\ & .20 \end{aligned}$ | $\begin{aligned} & 38.4 \\ & 53.4 \\ & 67.8 \end{aligned}$ | $\begin{aligned} & 23.4 \\ & 29.2 \\ & 34.6 \end{aligned}$ | $\begin{aligned} & 26.0 \\ & 38.4 \\ & 50.7 \end{aligned}$ | $\begin{aligned} & 10.4 \\ & 14.4 \\ & 18.3 \end{aligned}$ |
| 15 | $\begin{aligned} & .15 \\ & .20 \\ & .25 \end{aligned}$ | $\begin{aligned} & 44.0 \\ & 55.9 \\ & 67.5 \end{aligned}$ | $\begin{aligned} & 25.8 \\ & 30.3 \\ & 34.6 \end{aligned}$ | $\begin{aligned} & 30.7 \\ & 40.6 \\ & 50.5 \end{aligned}$ | $\begin{aligned} & 12.0 \\ & 15.1 \\ & 18.2 \end{aligned}$ |
| 18 | $\begin{aligned} & .20 \\ & .25 \\ & .30 \end{aligned}$ | $\begin{aligned} & 48.1 \\ & 57.9 \\ & 67.5 \end{aligned}$ | $\begin{aligned} & 27.6 \\ & 31.4 \\ & 34.9 \end{aligned}$ | $\begin{aligned} & 34.0 \\ & 42.3 \\ & 50.5 \end{aligned}$ | $\begin{aligned} & 12.8 \\ & 15.8 \\ & 18.3 \end{aligned}$ |
| 24 | $\begin{aligned} & .25 \\ & .30 \\ & .35 \end{aligned}$ | $\begin{aligned} & 47.9 \\ & 55.9 \\ & 63.7 \end{aligned}$ | $\begin{aligned} & 28.4 \\ & 31.5 \\ & 34.4 \end{aligned}$ | $\begin{aligned} & 33.4 \\ & 40.0 \\ & 46.6 \end{aligned}$ | $\begin{aligned} & 13.1 \\ & 15.2 \\ & 17.2 \end{aligned}$ |
| 30 | $\begin{aligned} & .30 \\ & .35 \\ & .40 \end{aligned}$ | $\begin{aligned} & 43.7 \\ & 49.7 \\ & 55.6 \end{aligned}$ | $\begin{aligned} & 26.7 \\ & 29.0 \\ & 31.3 \end{aligned}$ | $\begin{aligned} & 30.2 \\ & 35.2 \\ & 40.2 \end{aligned}$ | $\begin{aligned} & 12.2 \\ & 13.8 \\ & 15.3 \end{aligned}$ |
| S = Short-term design life ( 0.05 years) <br> $\mathrm{L}=$ Long-term design life ( 50 years) |  |  |  |  |  |

## $\begin{array}{ll}{[\text { [in GOOD SOIL }} & \text { SHORT TERM } \\ \text { U FAIR SOIL } & \text { LONG TERM }\end{array}$



FIGURE 5 Allowable fill height for 4-, 6-, and 8-in. pipes.

## Soil Quality

To interpolate between fair and good soil quality, Table 5 may be used with the following guidelines. Let Hf and Hg be the allowable fill heights for fair and good soil quality as read from the design tables or figures. Then for a selected intermediate soil quality listed in Table 5, the corresponding intermediate fill height, Hi , may be computed as
$H i=H f+r(H g-H f)$
where $r$ varies between 0 and 1.0 and is given in Table 5 as
a function of percent compaction for three classes of soil. These results were taken from a previous study (5).

## Design Life

For design lives of 50 years or more, the long-term allowable fill height is appropriate. If the design life is to be significantly less than 50 years, then the allowable fill height lies between the long- and short-term solutions. This can be estimated based on a linear log-log relationship in which the short-term
GOOD SOIL $\quad$ SHORT TERM
LOM SOIL


FIGURE 6 Allowable fill height for 10-, 12-, and 15-in. pipes.

## $\begin{array}{ll}\text { WOOD SOIL } & \text { SHORT TERM } \\ \text { M FAIR SOIL } & \text { LONG TERM }\end{array}$



FIGURE 7 Allowable fill height for 18-, 24-, and 30-in. pipes.
time period is taken as 0.05 years and the long-term as 50 years. Letting $H s$ and $H I$ represent the allowable fill heights for short- and long-term design periods, and denoting the actual design-life time as $t$, then the corresponding fill height, $H t$, is given by
$H t=H I(50 / t)^{\prime \prime \prime}$
where the exponent $m=\log (H s / H I) / 3$; here the divisor 3 comes from evaluating $\log (50 / .05)$.

## Example Design Problems

A 24 -in. plastic pipe with a sectional area of $0.3 \mathrm{in} .{ }^{2} / \mathrm{in}$. is to be in service for at least 50 years in a well-graded silty sand

TABLE 5 CORRESPONDENCE OF INTERPOLATION RATIO TO PERCENT COMPACTION

| Interpolation <br> Ratio <br> $r$ | Granular <br> SM <br> $\%$ | Mixed <br> SC <br> $\%$ | Cohesive <br> CL <br> $\%$ |
| :---: | :---: | :---: | :---: |
| (Fair) <br> 0.0 | 80 | 85 | 90 |
| 0.25 | 82 | 87 | 95 |
| 0.50 | 85 | 90 | 100 |
| 0.75 | 90 | 95 | NA |
| 1.00 |  |  |  |
| (Good) | 95 | 100 | NA |

SM = Silty Sand, Well Graded
SC = Silty Clayey Sand
CL = Clay (No Organic)
weighing $130 \mathrm{lb} / \mathrm{ft}^{3}$ at 85 percent relative compaction. Determine the maximum allowable burial depth.

Referring to Table 5 for a SM- 85 percent soil condition, it is determined that $r=0.5$. Using this value in Equation 4 along with $H f=15.2 \mathrm{ft}$ and $H g=31.5 \mathrm{ft}$ from the long-term fill heights in Table 4, the temporary result is that $H I=23.4$ ft . Readjusting this value for a density of $130 \mathrm{lb} / \mathrm{ft}^{3}$, the final answer is $H i^{*}=21.6 \mathrm{ft}$.

Now suppose the problem is to be reworked for a 2 -year design life, all else remains unchanged. The answer is given by Equation 5, in which $H I=21.6 \mathrm{ft}$ from above, and $H s$ is determined in the same manner using short-term fill height values to get $H s=44.3 \mathrm{ft}$. Thus, the exponent $m=0.104$, and the final allowable fill height for a 2-year service life is $H t=30.2 \mathrm{ft}$.

## CONCLUSION

The design results are applicable to all corrugated plastic pipe whose material properties conform to AASHTO specifications (2), whose sectional areas are within limits of Table 2, and whose corrugation height is at least $1 / 14$ of the diameter. Within the stated restrictions, the allowable fill heights may be used with conservative confidence.

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## REFERENCES

1. M. G. Katona. CANDE: A Modern Approach for the Structural Design and Analysis of Buried Culverts. Report FHWA-RD-775, Federal Highway Administration, Washington, D.C., Oct. 1976.
2. Soil-Plastic Pipe Interaction Systems. Section 18, American Association of State Highway and Transportation Officials Flexible Culvert Committee, San Francisco, Calif., Feb. 26, 1986.
3. Lars-Eric Janson. Investigation of the Long-Term Creep Modulus for Buried Polyethylene Pipes Subjected to Constant Deflection. Advances in Underground Pipeline Engineering. In Proc., International Conference, Pipeline Division, ASCE, Madison, Wis., Aug. 1985.
4. M. G. Katona. CANDE: A Versatile Soil-Structure Design and Analysis Computer Program. Journal of Advances in Engineering Software, Vol. 1, No. 1, 1978. pp. 3-9.
5. M. G. Katona. CANDE-1980: Box Culverts and Soil Models. Report FHWA-RD-172, Federal Highway Administration, U.S. Department of Transportation, May 1981.
6. M. G. Katona and A. Y. Akl. Design of Buried Culverts with Stress-Relieving Joints. In Transportation Research Record 1129, TRB, National Research Council, Washington, D.C., 1987, pp. 39-54.
7. R. K. Watkins, J. M. Dwiggins, and W. E. Altermatt. Structural Design of Buried Corrugated Polyethylene Pipes. In Transportation Research Record 1129, TRB, National Research Council, 1987, pp. 12-20.

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