GEOSYNTHETIC CONFINED PRESSURIZED SLURRY (GeoCoPS):

Supplemental Notes

For Version 1.0

by

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1.0 INTRODUCTION

Construction in environmentally sensitive areas (e.g., wetlands) requires techniques causing minimum disturbance and damage. One such technique can be achieved with the aide of dikes made of geosynthetic tubes. The flat tube can be placed manually followed by slurry pumped into it. The quickly-formed dike then may retain water on one side while allowing construction on the other. Over time, vegetation may grow over the tube exposed surface. Tubes can also be used to contain and cap contaminated soil. They can be used to form a 'working table' over very soft soil and thus, allowing the construction of an embankment. Tubes filled with mortar or sand have been used to construct groins to control beach erosion. Some interesting case histories are reported by Silvester (1986), Bogossian et al. (1982), Perrier (1986) and Ockels (1991).

Tubes are made of sewn geosynthetic sheets. Inlet openings on top allow for the attachment of a pipe that transports hydraulic fill into the tube. If the fill is sandy and the geosynthetic is very pervious (e.g, geotextile), these inlets should be spaced closely (say, 30 feet apart) to assure a uniform fill up of the tube (i.e., water will seep through the tube thus cease transporting the sand over a short distance). If clayey slurry is used, the inlets can be located as far as 500 feet apart. Simply, the fine clayey particles tend to rapidly blind the fabric slowing down the water escape through the geotextile.

The scope of this note is limited to the design aspect of selecting a geosynthetic. Important aspects associated with actual construction are available in the literature (e.g., Pilarczyk, 1994, and Sprague, 1993). To assure successful installation, construction aspects must be accounted for in the design (e.g., locations and type of inlet to tube).

1.1 Computer System Requirements

GeoCoPS (version 1.0) is written in Fortran and is compiled with Microsoft© PowerStation Compiler. This compiler utilizes a 32 bit environment, using memory outside DOS domain. It achieves this by invoking a DOS extender program, called DOSXMSF.EXE, which must be present in the directory path of GeoCoPS. Results can be printed using any printer that is compatible with the system and is connected to the first parallel port (i.e., LPT1). If the printer is graphically compatible with the system through DOS, the displayed image can also be printed by using the 'Print Screen' key. In this case it is recommended to first change the setup toggle within GeoCoPS to display the image in black and white. Alternatively, if the printer is HP LaserJet© (or compatible), having a 300 by 300 dpi, the image can be sent directly using GeoCoPS menu. Furthermore, GeoCoPS allows the user to capture the image as a PCX data file. Upon exiting GeoCoPS, the user can access this PCX file with nearly all commercially available graphics software, edit the image if necessary, and then print it using the particular software utilized.

To run properly, GeoCoPS requires at least 2MB RAM and an IBM© PC compatible system with 386 or higher processor. A math coprocessor is *practically* needed to run the program since it is computationally intensive. The operating system should be DOS 4.00 or higher. The display screen should be a VGA or better (i.e., have 640 by 480 pixels or higher). To obtain maximum effects, a color display is recommended. For best quality of printed output, a laser printer is recommended.

2.0 OVERVIEW OF ANALYSIS

Formulation of a geosynthetic tube, filled with pressurized slurry or fluid, is based on equilibrium of the geosynthetic shell. The results of this formulation provide both the circumferential tensile force in, and the cylindrical geometry of the encapsulating shell material. It should be pointed out that the formulation appears in numerous articles (e.g., Liu 1981, Kazimierowicz 1994, Carroll 1994). For the sake of completeness, only an overview of the basic formulation is reproduced hereinafter.

The following assumptions govern the formulation:

1. The problem is two dimensional (i.e., plane strain) in nature. That is, the tube is long and all cross sections perpendicular to the long axis are identical in terms of geometry and materials.

2. The geosynthetic shell is thin, flexible and has negligible weight per unit length.

3. The material filling the tube is a slurry (i.e., a fluid) and therefore, within it a hydrostatic state of stresses exists.

4. There are no shear stresses developing between the slurry and the geosynthetic.

Refer to Figure 1 for notation and convention. For clarity of presentation, the tube considered is surrounded by air and is filled with only one type of slurry. However, extension of the formulation to include layers of slurry inside and layers of fluid outside, is straightforward. In fact, GeoCoPS can accommodate two layers of slurry (each having a different density to account for slurry pumping at different times) and two layers of outside fluid (to account for the effects of partial or full submergence of the tube in

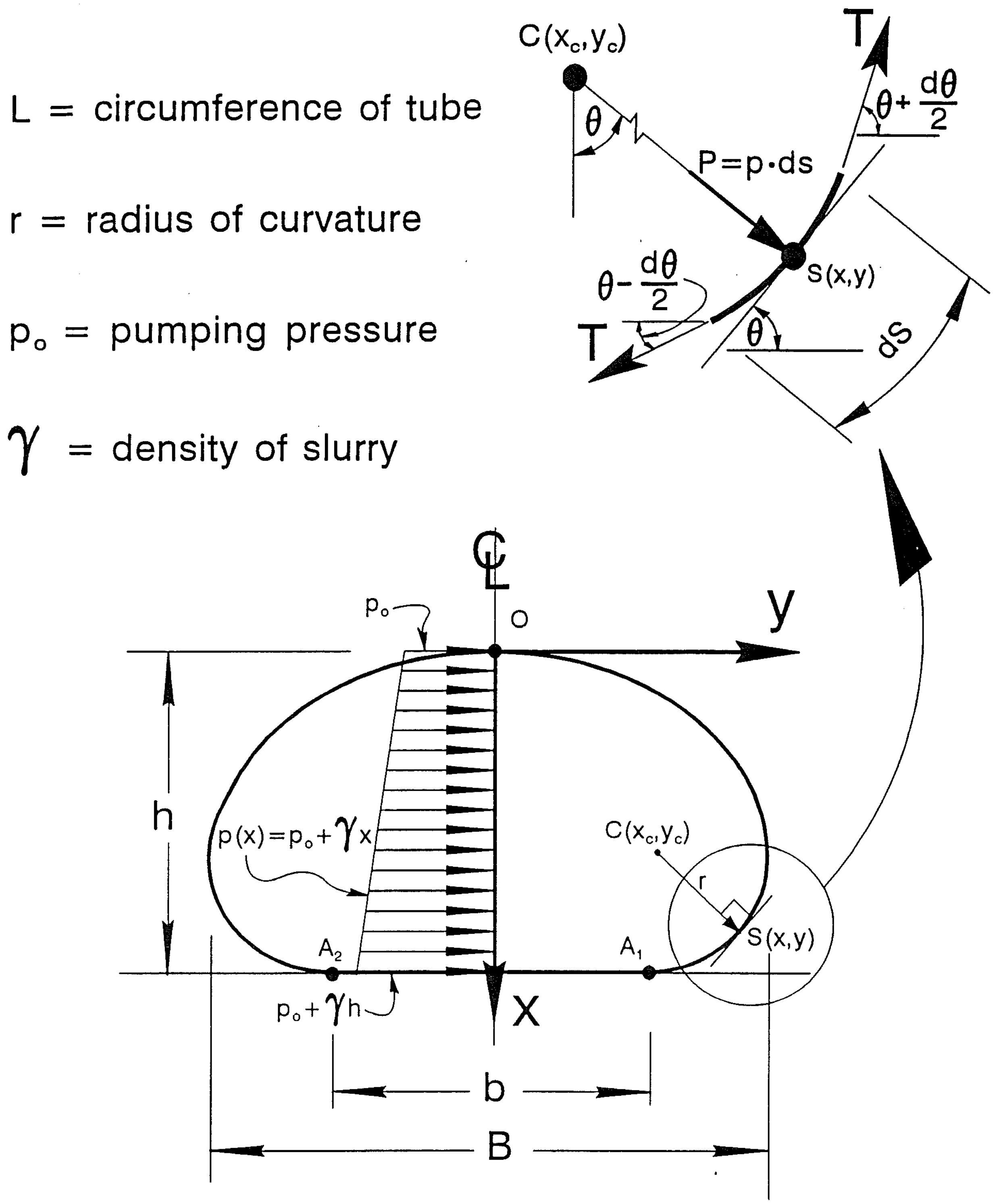


Figure 1. Cross sectional view of geosynthetic tube: convention and notation

water). Note that the cross section is symmetrical, having a maximum height of h at the centerline, some maximum width B, and a flat base that is in contact with the foundation soil and is b wide. The pumping pressure of the slurry into the tube is p_o and its average density is γ. Hence, the hydrostatic pressure of the slurry at any depth x, as measured from point O, is $p(x)=p_o+\gamma x$.

The geometry of the geosynthetic shell is defined by an unknown function $y=f(x)$. At a point of contact $S(x,y)$, the radius of curvature of the geosynthetic is r. The center of this curvature is at point $C(x_c,y_c)$. Note that both r and C vary along $y(x)$. Consider the forces on an infinitesimal arc length, ds, of the geosynthetic at S (see inset in Figure 1). Since it was assumed that the problem is two dimensional and that no shear stresses develop between the slurry and the geosynthetic, it follows that the geosynthetic tensile force, T, must be constant along the circumference. Assembling the force equilibrium equation in either x or y direction leads to the following relationship:

$$r(x) = \frac{T}{p(x)} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

Equation 1 is valid at any point along A_1OA_2. To simplify the analysis, it is assumed (conservatively) that the calculated T from Equation 1 is carried solely by the geosynthetic along the flat base b (i.e., no portion of T is transferred to the foundation soil due to shear along the interface between the geosynthetic and soil; this shear can be mobilized only as the geosynthetic deforms relative to the foundation). Consequently, Equation 1 expresses the complete solution for the problem. From differential calculus, the radius of curvature can be written as:

$$r(x) = \frac{[1+(y')^2]^{2/3}}{y''} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where $y'=dy/dx$ and $y''=d^2y/dx^2$.

Substituting Equation 2 and $p(x)$ into Equation 1 yields:

$$T \cdot y'' - [\, p_o + \gamma \cdot x \,] \cdot [\, 1 + (y')^2 \,]^{3/2} = 0 \quad \ldots\ldots\ldots\ldots \quad (3)$$

Equation 3 is a non-linear differential equation that, in general, has no closed-form solution. That is, it has to be solved numerically. Its solution produces the relationships between the geometry of the tube $y(x)$, the circumferential tensile force T, the pumping pressure p_o, the unit weight of the slurry γ and the height of the tube h (note that x varies only between zero and h):

$$y = f(\, x \mid T, p_o, h, \gamma) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Since the unit weight of the slurry γ is known, Equation 4 implies that y is a function of the independent variable x and the three parameters T, p_o and h. Typically, $y(x)$ is sought for a given (design) parameter; i.e., either T, or p_o or h is given. That is, the other two parameters are part of the solution of the problem. Therefore, to obtain such an explicit solution, constraints must be imposed. Two such constraints will produce a solution where for a selected design parameter, the geometry of the tube, as well as the other two parameters, will be obtained. That is, two physical constraints will replace two unknown parameters that currently are part of the solution.

One constraint is the geometrical boundary condition at point O. Physically, the geosynthetic at O must be horizontal to assure a smooth transition from one half tube of the symmetrical problem to the other half. That is:

$$1 / y'(0) = 0 \qquad (5)$$

The second constraint can be introduced through the specification of the flat base length b. In this case, vertical force equilibrium along b requires that:

$$b = \frac{W}{p_o + \gamma \cdot h} \qquad (6a)$$

where W is the weight, per unit length, of the slurry filling the entire section of the tube:

$$W = 2\,\gamma \int_0^h y(x) \cdot dx \qquad (6b)$$

Combining Equations 6a and 6b gives:

$$b = \frac{2\,\gamma}{p_o + \gamma\, h} \int_0^h y(x)\; dx \qquad (7)$$

Prescribing b and simultaneously solving Equations 3, 5 and 7 for a single selected design parameter (either T, or p_o or h) will result in a tube having a certain length of circumference L. However, it is more practical to specify the circumference of a tube rather than b since the tube is manufactured from a selected number of geosynthetic sheets sewn together. If L is specified, the value of b then will be the outcome of the analysis. Hence, Equation 7 can be replaced by the following constraint:

$$L = b + 2 \int_s ds \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (8)$$

where ds is the arc length and, from differential calculus, is equal to $[1+(y')^2]dx$. Using this definition of ds in Equation 8 combined with substitution of Equation 7 (i.e., this equation represent the vertical force equilibrium along b) result in:

$$L = \frac{2\gamma}{p_o + \gamma h} \int_0^h y(x)\, dx + 2 \int_0^h [\, 1 + (y')^2 \,]^{1/2}\, dx \quad \dots\dots \quad (9)$$

Now, for a prescribed L, simultaneous solution of Equations 3, 5 and 9 will yield the relationship between T, h, p_o and $y(x)$; i.e., will yield Equation 4. This solution will be numerically explicit if one of the design parameters (either T or h or p_o) will be specified. The numerical process involved with such a solution is rather tedious requiring a trial and error procedure. Several computational schemes are available in the literature (e.g., Liu 1981, Kazimierowicz 1994, Carroll 1994). However, none of these procedures follows the practical scheme described in this report [that is, for given circumference L, and say, T (or h or p_o), find the geometry of the tube $y(x)$ and the other two parameters]. Hence, a modified procedure was developed in GeoCoPS. The procedure utilized in GeoCoPS is a modification of that proposed by Carroll (1994).

Finally, there is also a practical need to assess the axial tensile force per unit length, T_{axial}, in the geosynthetic encapsulating the slurry. Refer to Figure 2 for definition

T = circumferential geosynthetic tensile force (Equation 3)

T_{axial} = axial geosynthetic tensile force (Equation 11)

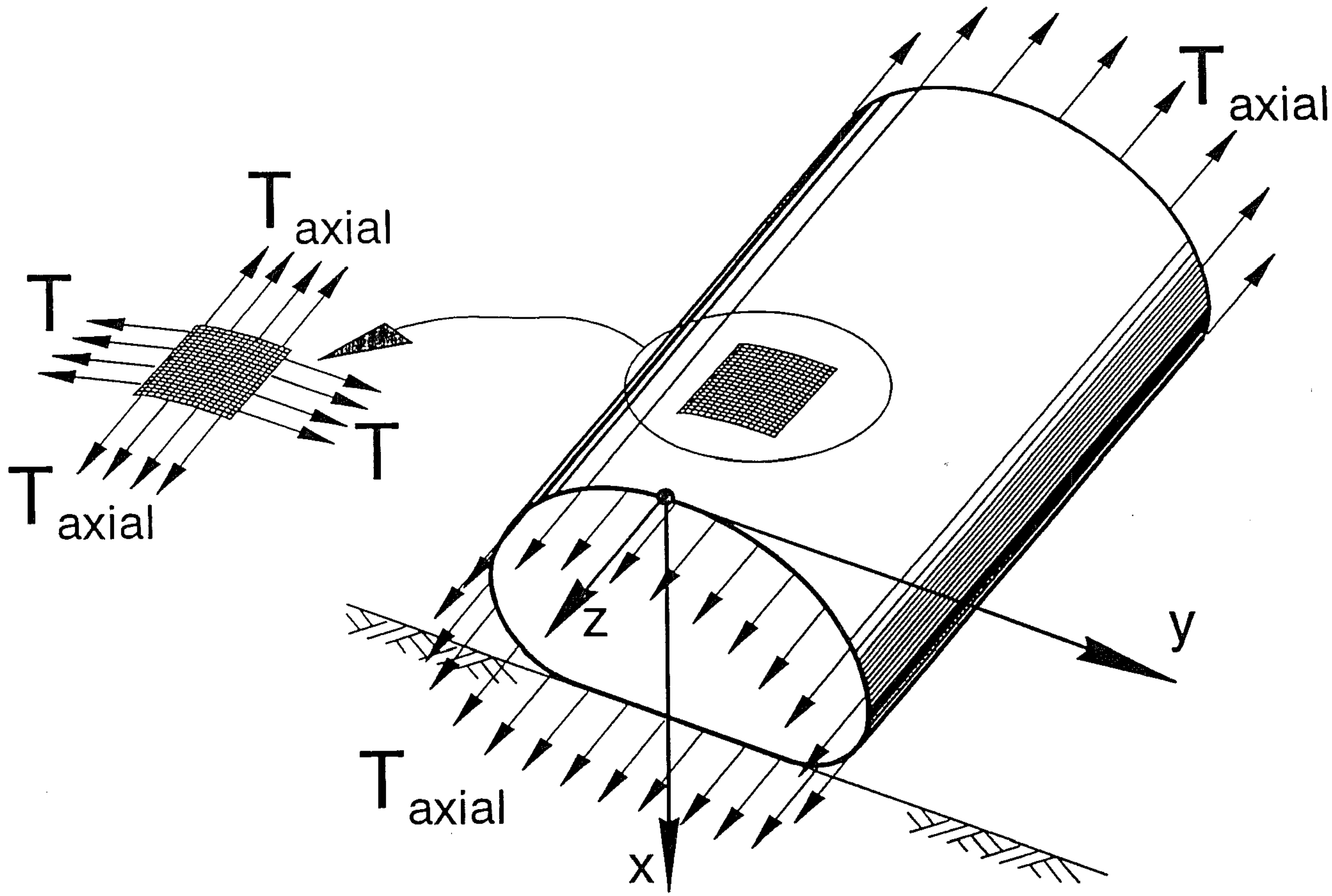


Figure 2. Axial tensile force in geosynthetic tube

of this force. The total force P acting on a vertical plane signifying the end of a tube, resulting from pressurized slurry, is:

$$P = 2 \cdot \int_0^h (p_o + \gamma\ x) \cdot y(x) \cdot dx \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

The force P is carried by the tube in the z-direction (i.e., axial direction). The force T_{axial} per unit length then is P divided by the circumference, L, of the tube. That is:

$$T_{axial} = \frac{2}{L} \int_0^h (p_o + \gamma\ x)\ y(x)\ dx \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

Once the geometry of the tube has been determined through the solution of Equation 3, the value of T_{axial} can be computed by solving Equation 11.

Typically, the circumferential force T will be larger than T_{axial}. Hence, if a geosynthetic having isotropic strength is considered, the value of T_{axial} is not needed in design. However, frequently geosynthetics are anisotropic; i.e., their strength in the warp direction is different than that in the fill direction. This anisotropy is particularly common in medium to high strength geotextiles, where different types and number of yarns per unit width are used in each of the principal directions in the fabrication process. The end product may have either significantly higher or worse, lower, strength in the axial direction as compared to the circumferential one. Consequently, to assure economical selection of a geosynthetic, producing a safe structure, the value of T_{axial} should always be considered. GeoCoPS provides the values of both T and T_{axial}.

3.0 VERIFICATION OF ANALYSIS

3.1 Numerical

Silvester (1986) presented the results of a numerical analysis in a format of a non-dimensional chart and a table for a particular circumference of a tube. It is stated that the numerically resulted shapes of the tube have been verified experimentally. The references imply the experimental work used for verification was conducted by Liu, some of which are reported by Liu (1981). The input data for the tabulated results was the circumference, L=12 feet, and the pressure at the bottom of the tube (i.e., $p=p_o+\gamma h$); the unit weight of the slurry used (mortar) relative to that of water was 2.0. Table 1 shows the comparison between values calculated by Silvester (1986) and those computed using GeoCoPS for the same input data. As evident from the table, the numerical agreement of computed results is very good.

Liu (1981) showed the results of analysis and experimental work. Two types of slurry were used: water and mortar. One reported case was for a tube filled with mortar and submerged in water. No values of calculated T were reported. Table 2 indicates once again a very good numerical agreement.

Kazimierowicz (1994) presented an instructive numerical approach to solve the problem. Table 3 shows a comparison of results for one type of slurry and different pumping pressures. Generally, the agreement here is good.

Table 1. Comparison of results obtained from GeoCoPS and Silvester (1986) [Given L; $p=p_o+\gamma h$; and $\gamma_{slurry}=2\gamma_w$. See Fig. 1 for notation]

	Input		Calculated					
No.	L [ft]	p [psi]	Source	h [ft]	b [ft]	B [ft]	Area [ft^2]	T [lb/ft]
1	12.0	6.46	Silvester	3.28	1.58	4.17	11.30	1202
			GeoCoPS	3.28	1.51	4.17	11.22	1191
2	12.0	4.38	Silvester	2.95	2.13	4.33	10.66	693
			GeoCoPS	2.99	2.11	4.33	10.71	667
3	12.0	3.22	Silvester	2.62	2.69	4.53	10.23	397
			GeoCoPS	2.68	2.73	4.54	10.14	397
4	12.0	2.62	Silvester	2.30	3.08	4.76	9.58	286
			GeoCoPS	2.46	3.13	4.70	9.68	286
5	12.0	1.99	Silvester	1.97	3.45	4.92	8.72	194
			GeoCoPS	2.06	3.76	4.98	8.70	165
6	12.0	1.68	Silvester	1.64	3.97	5.09	7.97	139
			GeoCoPS	1.81	4.09	5.12	7.93	117

Table 2. Comparison of results obtained from GeoCoPS and Liu (1981)
[Given L; $p=p_o+\gamma h$; and γ. See Fig. 1 for notation]

	Input			Calculated				
No.	L [ft]	p [psi]	γ_{slurry} [pcf]	Source	h [ft]	b [ft]	B [ft]	d[1] [ft]
1[3]	3.04	0.560	62.4	Liu[2]	0.76	0.60	1.10	0.30
				GeoCoPS	0.76	0.54	1.11	0.31
2[3]	3.04	0.255	62.4	Liu[2]	0.52	1.03	1.26	0.17
				GeoCoPS	0.53	0.96	1.26	0.17
3[4]	3.41	0.498	124.8	Liu[2]	0.80	0.82	1.34	0.30
				GeoCoPS	0.81	0.80	1.36	0.30

(1) *d* = height above base where maximum width of tube, B, occurs

(2) Values taken from graphical presentation

(3) No water outside tube

(4) Tube is filled with mortar and is submerged in water

Table 3. Comparison of results obtained from GeoCoPS and Kazimierowicz (1994)
[Given L; p_o; and $\gamma_{slurry}=1.4\gamma_w$. See Fig. 1 for notation]

	Input		Calculated			
No.	L [ft]	p_o [psi]	Source	h [ft]	b [ft]	T [lb/ft]
1	12.0	2.53	Kazimierowicz	3.28	1.51	808
			GeoCoPS	3.29	1.51	835
2	12.0	2.95	Kazimierowicz	2.95	2.10	466
			GeoCoPS	3.00	2.12	472
3	12.0	0.66	Kazimierowicz	2.62	2.76	275
			GeoCoPS	2.70	2.69	287
4	12.0	0.44	Kazimierowicz	2.30	3.15	188
			GeoCoPS	2.52	3.05	218

These comparisons are for results obtained from different numerical procedures solving, essentially, the same governing equation (i.e., Equation 3). The closeness of results can serve as an indication that the numerical procedure utilized in GeoCoPS leads to the correct geometry and the associated tensile force (within an acceptable numerical margin of error).

3.2 Experimental

Liu (1981) conducted experiments on PVC tubes, each 8.2 feet long filled either with water or mortar. The mortar-filled tubes were submerged in water. The tubes were supported by a transparent Plexiglas 'foundation' so that *b* could be measured accurately. Liu also traced the geometry of the tube. Figure 3 through 5 show the measured points along the circumference versus the calculated geometry by GeoCoPS. Note that the three cases also correspond to the presentation in Table 2; however, in the figures the comparison is restricted to experimental data.

Clearly, the agreement between predictions and measured data is very good. This increases the confidence in the practical value of the analysis and its associated numerical procedure and thus, making GeoCoPS a suitable tool for designing geosynthetic tubes subjected to slurry pressure.

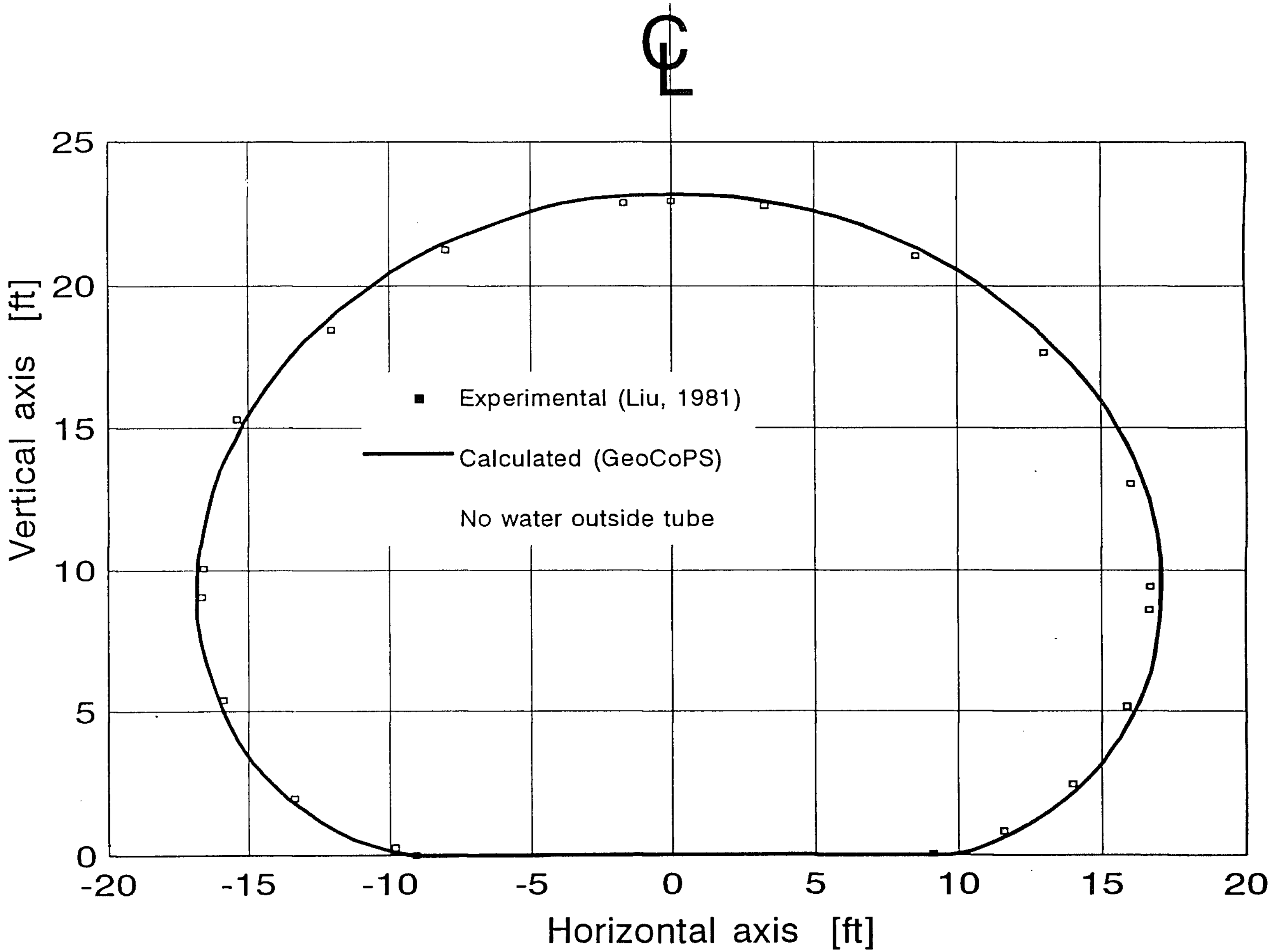


Figure 3. Measured points along circumference tube (Liu, 1981) versus computed geometry by GeoCoPS ($L=3.04$ ft; $p=p_o+\gamma h=0.56$ psi; $\gamma_{slurry}=\gamma_w$)

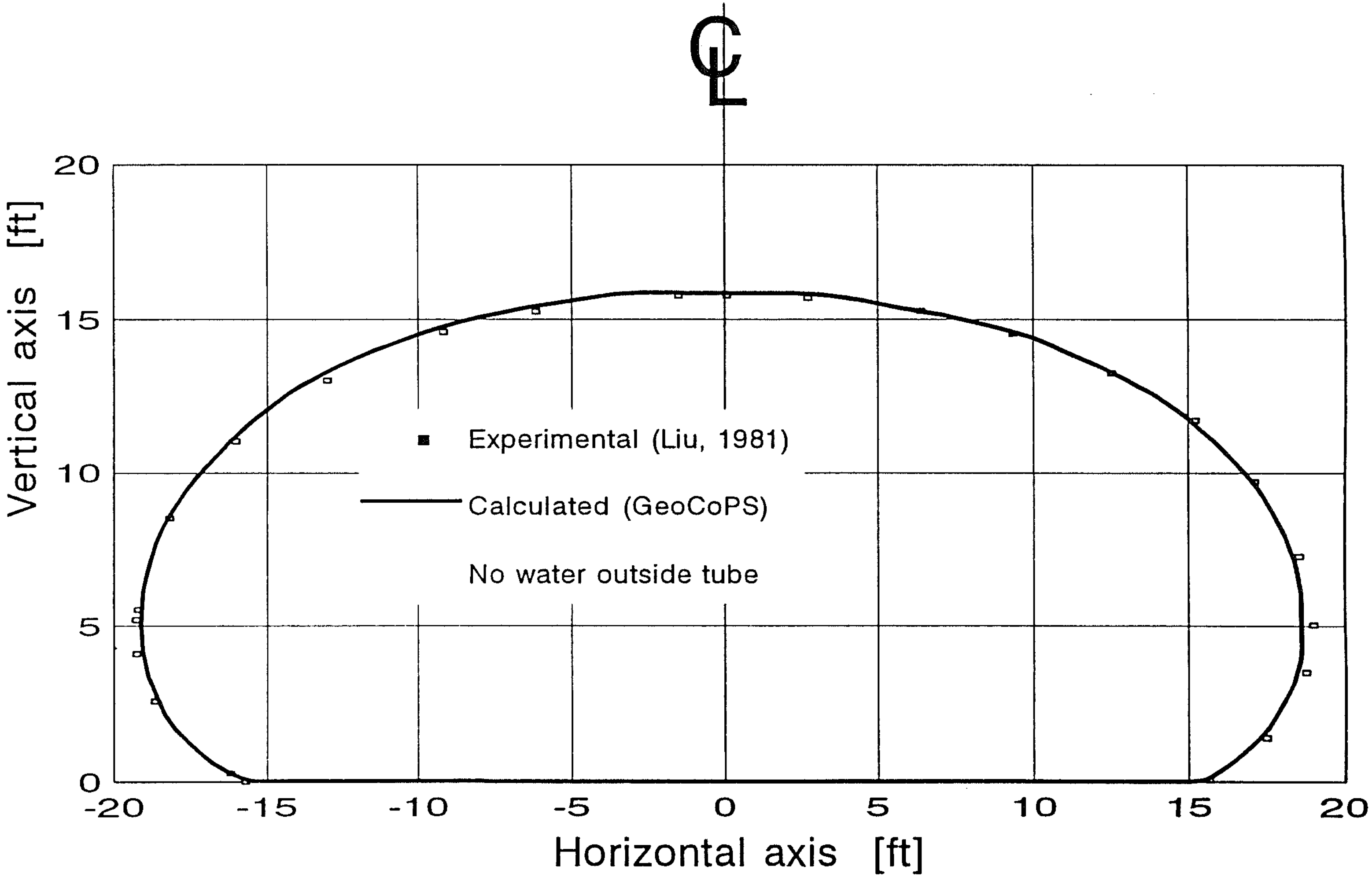


Figure 4. Measured points along circumference tube (Liu, 1981) versus computed geometry by GeoCoPS (L=0.59 ft; $p=p_o+\gamma h=0.25$ psi; $\gamma_{slurry}=\gamma_w$)

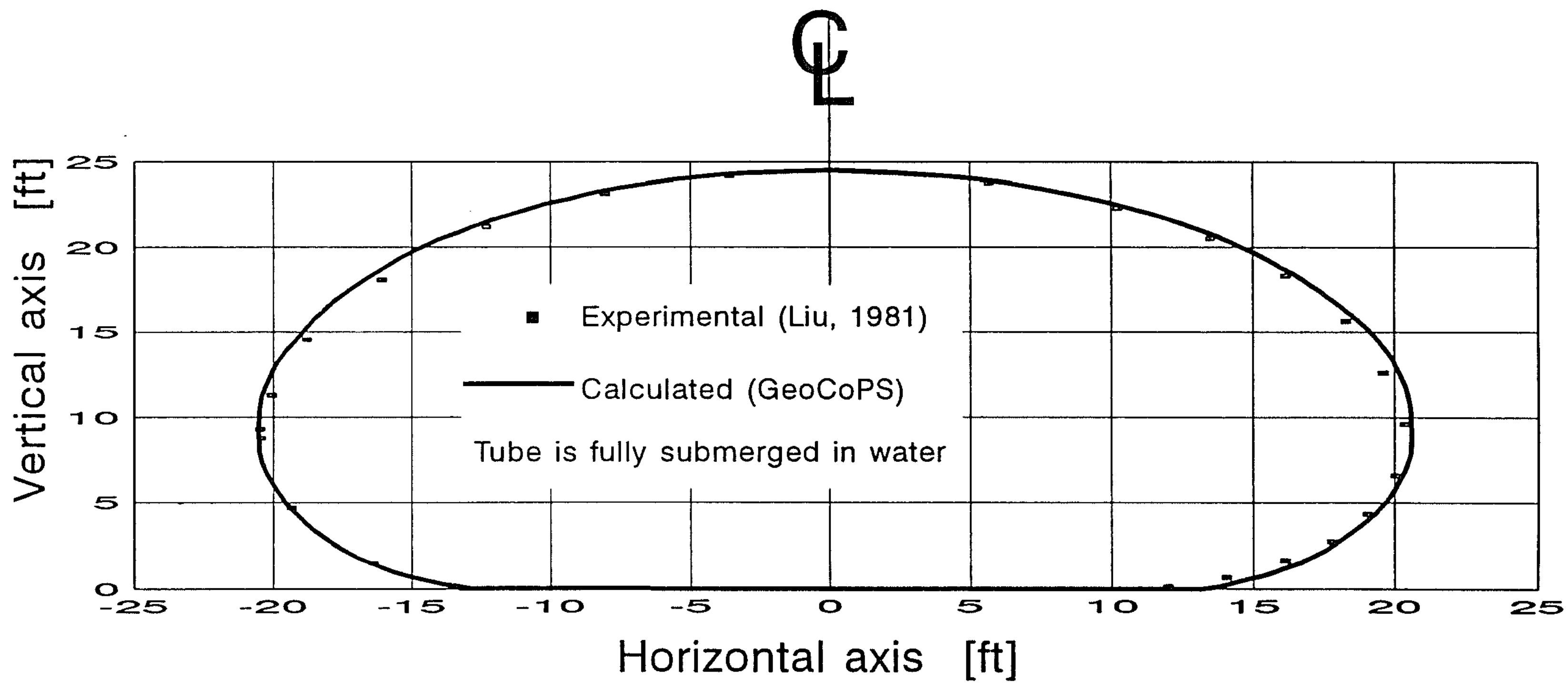


Figure 5. Measured points along circumference tube (Liu, 1981) versus computed geometry by GeoCoPS (L=1.15 ft; $p=p_o+\gamma h=0.50$ psi; $\gamma_{slurry}=2\cdot\gamma_w$)

4.0 PARAMETRIC STUDY

To realize how sensitive the solution for the geosynthetic tube is with respect to the design parameters, a parametric study was conducted. This instructive study was conducted using GeoCoPS. For all cases, the circumference of the tube was chosen as L=30 feet, the unit weight of slurry relative to water was taken as 1.2, no water outside the tube was considered, and all safety factors on geosynthetic strength were set to 1.0.

Figure 6 shows the effects of the specified tensile force of the geosynthetic (circumferential strength) on the geometry of the tube. Note that to get a perfect circular cross section, having a diameter equal to $D=L/\pi=9.55$ feet, the required T (or p_o) must approach infinity. However, at T as low as 1,000 lb/ft the height h is 6.0 ft; i.e., h is 63% of the maximum theoretical height D. Increasing T to 6000 lb/ft will produce a height of 8.5 feet or 89% of D. Note that there is little influence on the cross sectional area as the height changes. This has clear design implications if storage of a certain volume of slurry is needed.

Figure 7 illustrates the effects of a designed height h on the geometry of the tube. For a desired height of 3.0 feet (about 31% of D), the required pumping pressure is nearly zero and the required circumferential force is small. However, for a desired height of about 94% of D (h=9.0 feet), the required pumping pressure is about 17.8 *psi* and the required circumferential force is substantially larger than before.

Figure 8 depicts the effects of the pumping pressure on the geometry of the tube. It is apparent that at low pressures, a small increase in p_o will result in significant increase in height h. However, beyond a certain value (say, 5 *psi*), the increase in height is

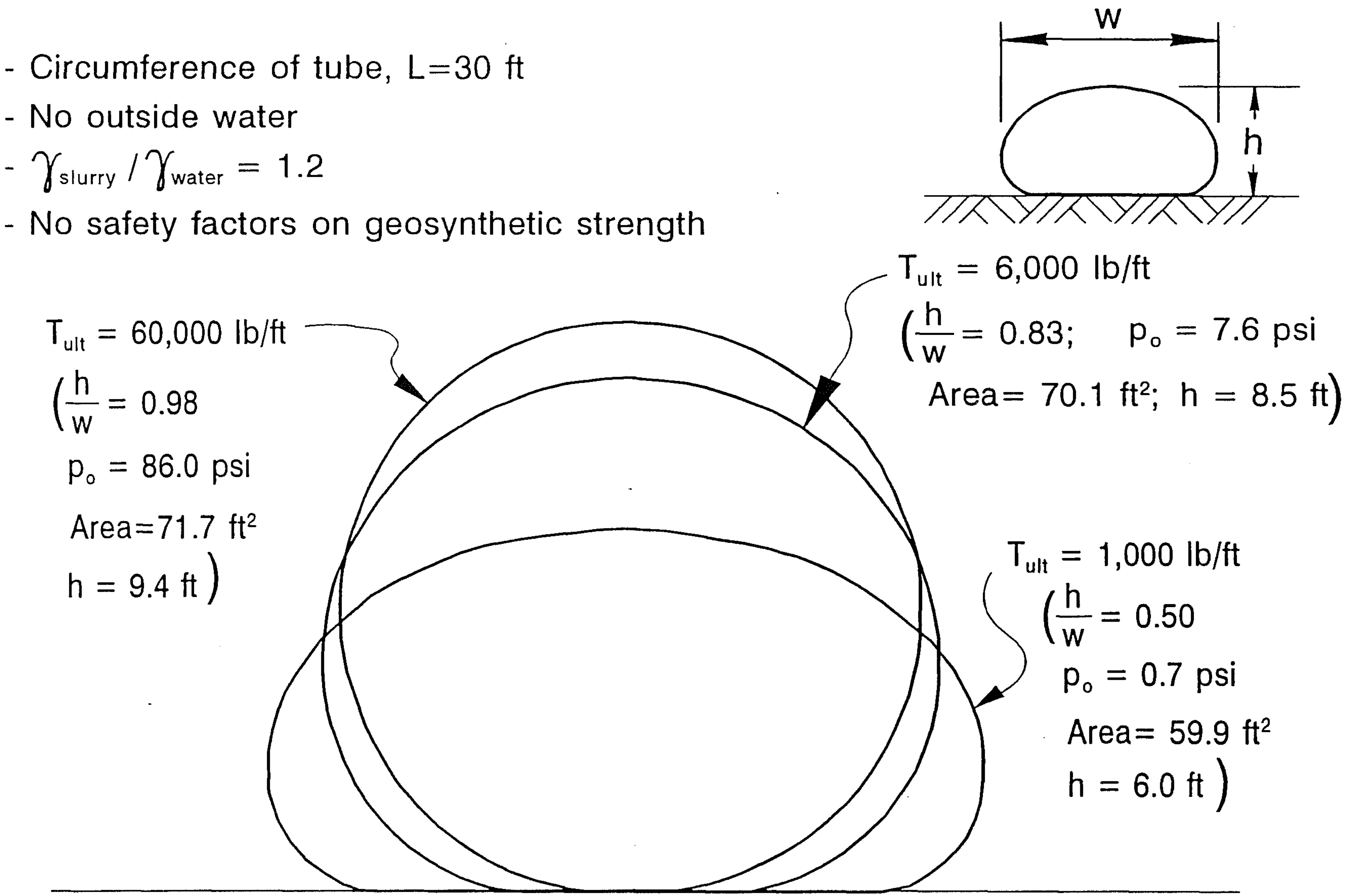
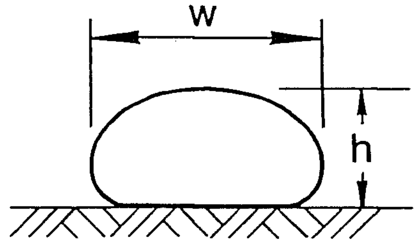


Figure 6. Effects of T_{ult} on geometry of tube

- Circumference of tube, L=30 ft
- No outside water
- $\gamma_{slurry} / \gamma_{water} = 1.2$
- No safety factors on geosynthetic strength



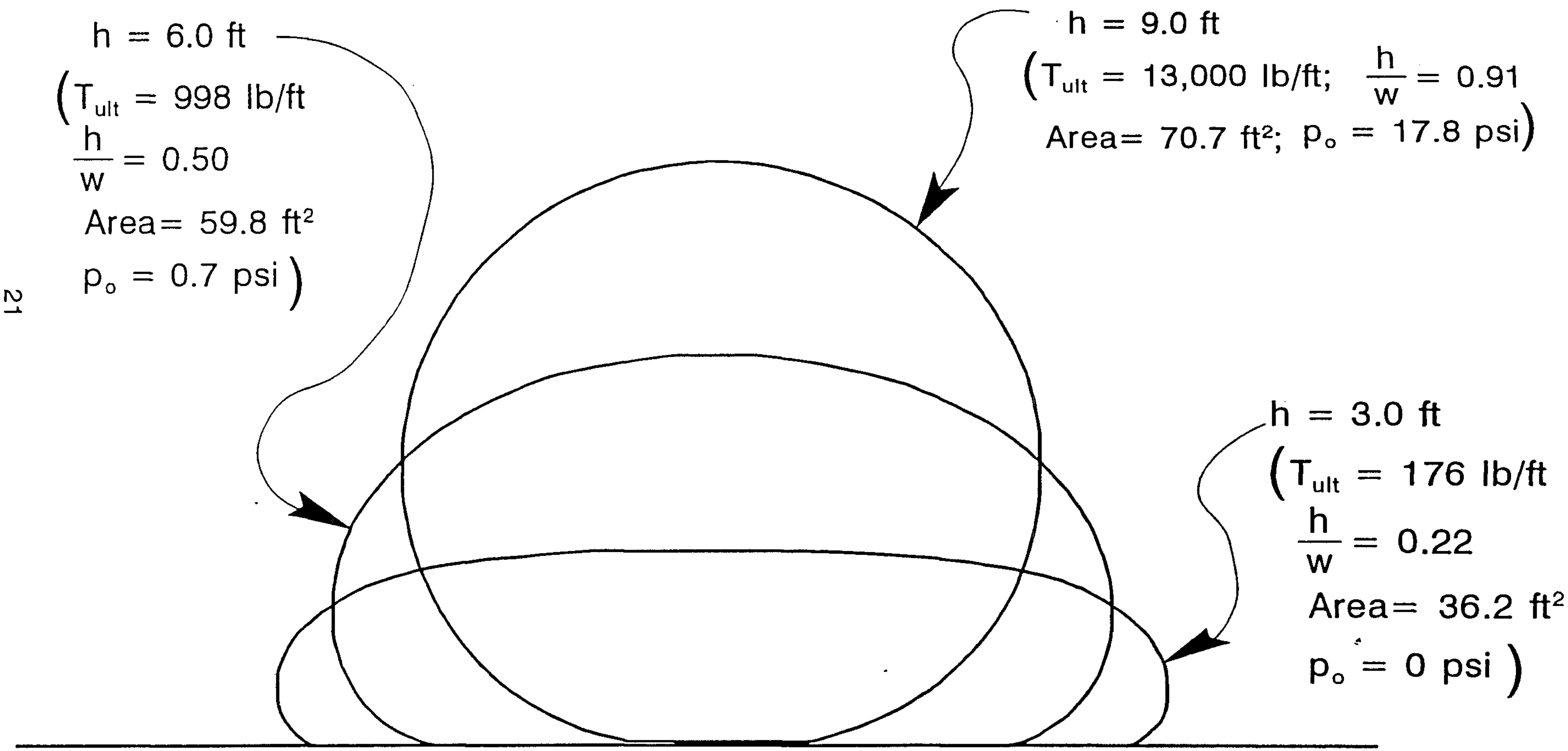
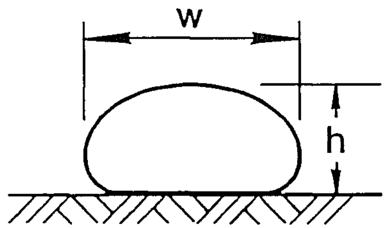


Figure 7. Effects of h on geometry of tube

- Circumference of tube, L=30 ft
- No outside water
- $\gamma_{slurry} / \gamma_{water} = 1.2$
- No safety factors on geosynthetic strength



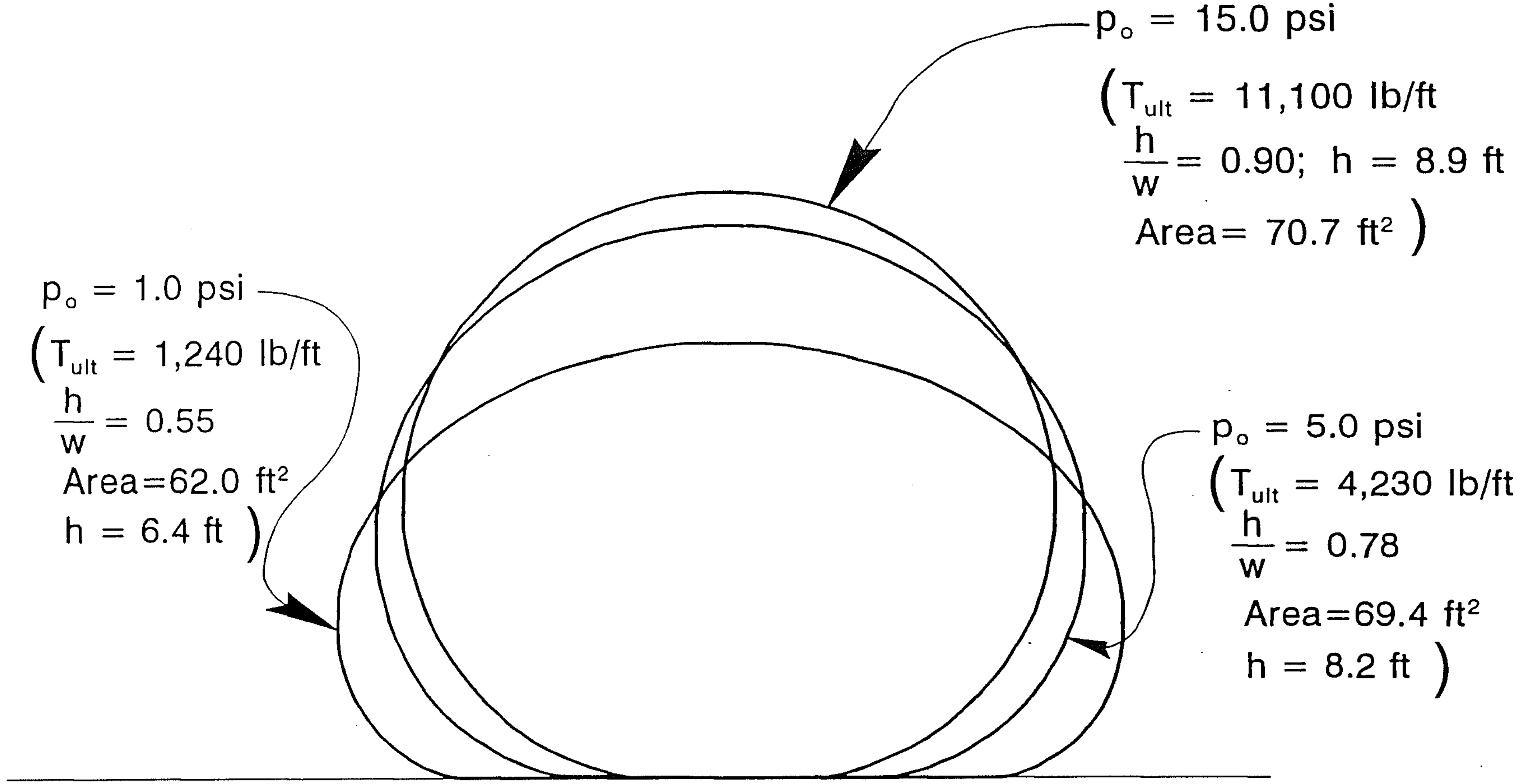


Figure ~~4-3~~ 8 Effects of p_o on geometry of tube insignificant while the increase in required strength of geosynthetic is exponential.

Figure 9 demonstrates the relationship between the height of the tube and the pumping pressure. It can be seen that p_o is most significant at low pressures; as the pressure increases, its effect on h become negligible. In fact, the relationship approaches an asymptote of $h=D$ that will be met only when p_o is at infinity.

Figure 10 illustrates the effects of pumping pressure on both T and T_{axial}. For the selected parameters in the parametric study, it can be seen that as p_o decreases, the axial force approaches the value of the circumferential force. This figure is particularly instructive in the context of design; it illustrates the potential economy when selecting a geosynthetic having an anisotropic strength that correspond to both tensile forces, T and T_{axial}, when those are significantly different.

Finally, Figures 11 and 12 show the maximum and minimum feasible height of a tube having a given circumference L. The maximum value, h_{max}, is equal to the diameter of a tube having a circular cross section and a circumference L. The minimum feasible height, h_{min}, was calculated using GeoCoPS. It corresponds to a case where the pumping is just zero and yet the cross section of the tube is full. In other words, it signifies the limit for which no change in the direction of the curvature of the encapsulating tube occurs (i.e., no "sagging" of the tube occurs at its top). Such a change will render the mathematical solution of the problem of pressurized slurry tube invalid. Physically, it implies the tube section is not full making the specified circumference not relevant (i.e., too long). Figures 11 and 12 indicate the range of feasible heights for given circumferences. Note that when the tube is not submerged (Figure 11), the slurry density

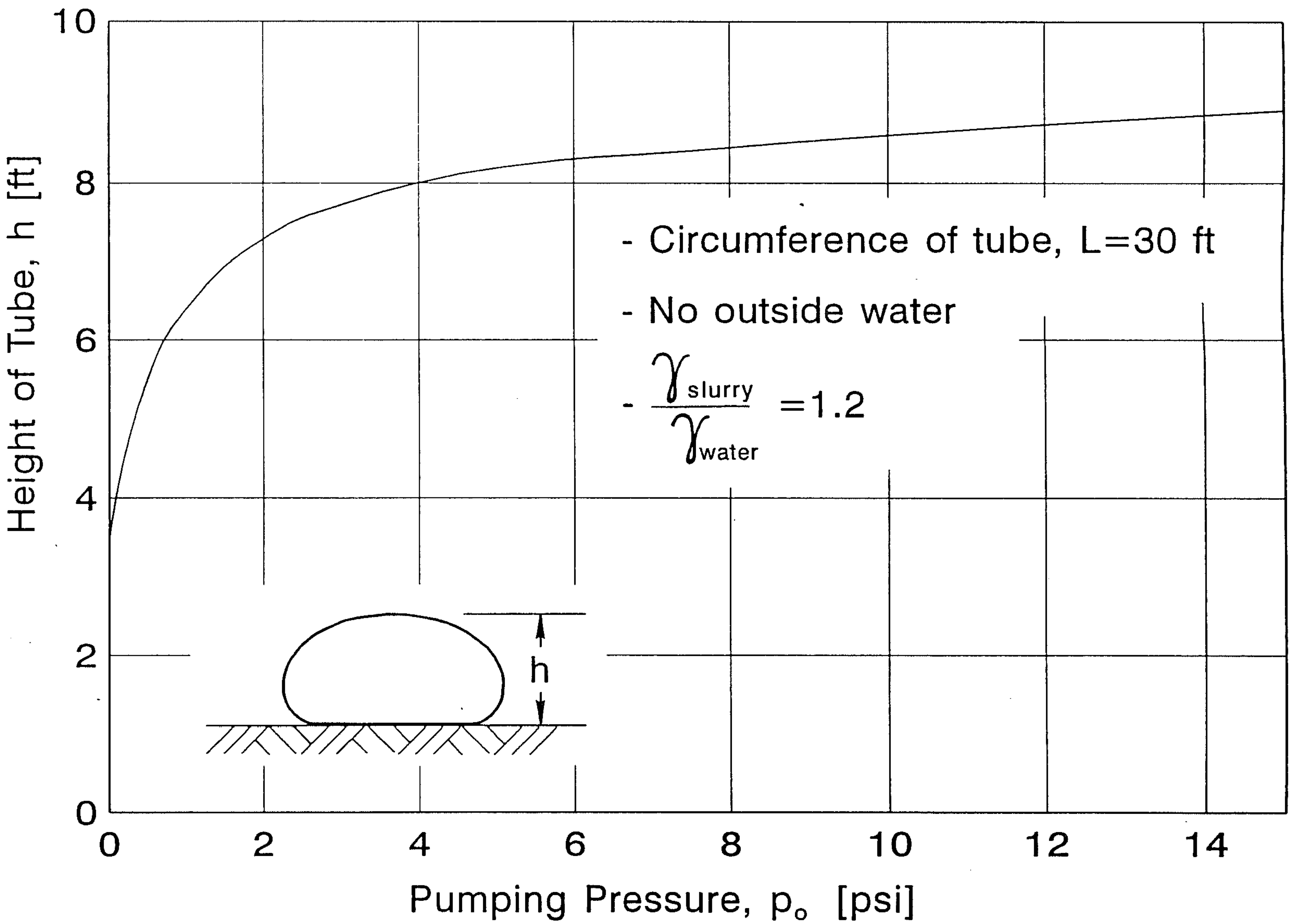


Figure 9. Height of tube versus pumping pressure

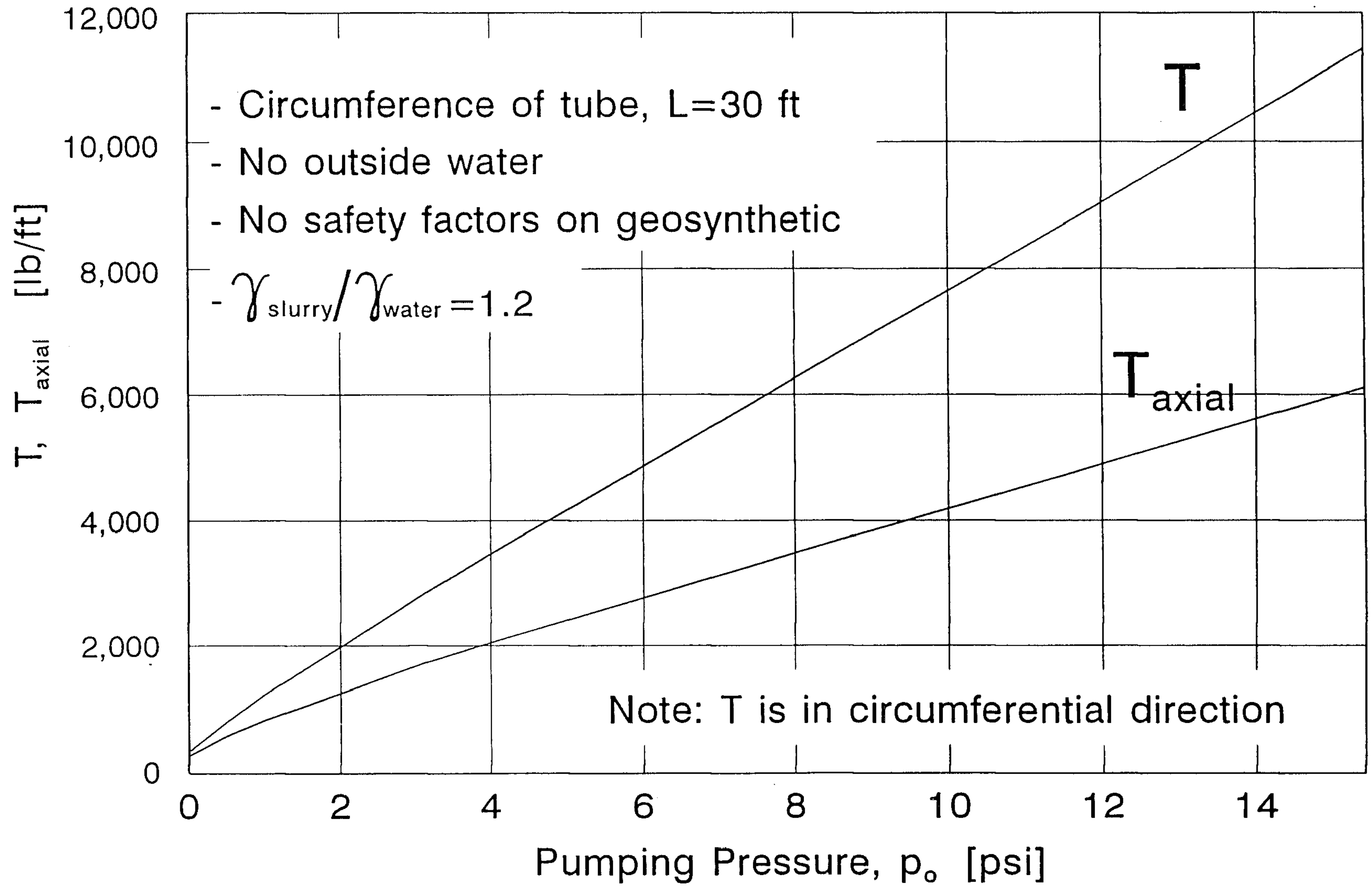


Figure 10. T and T_{axial} versus pumping pressure

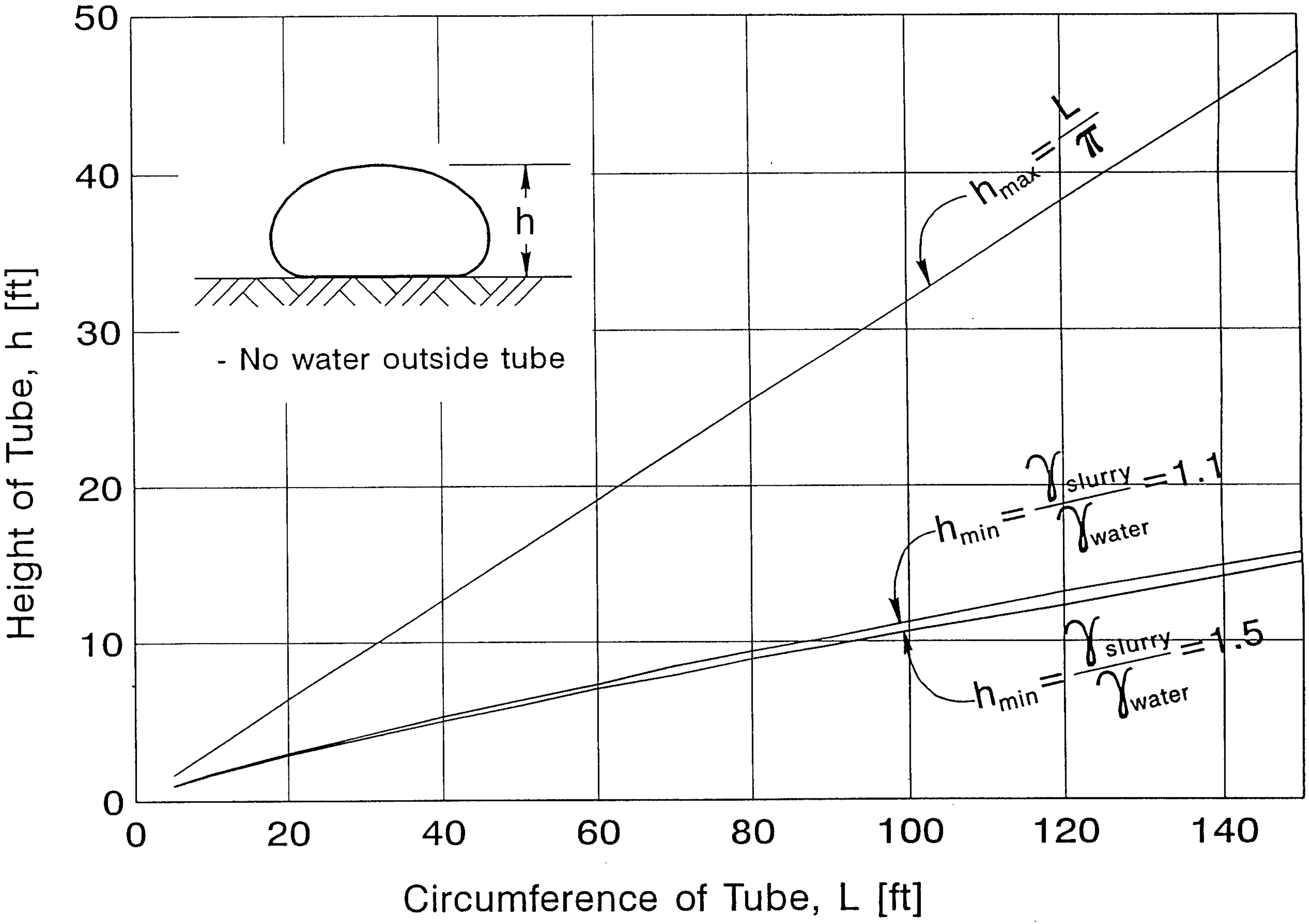


Figure 11. Extreme values of feasible heights of tube (No water outside)

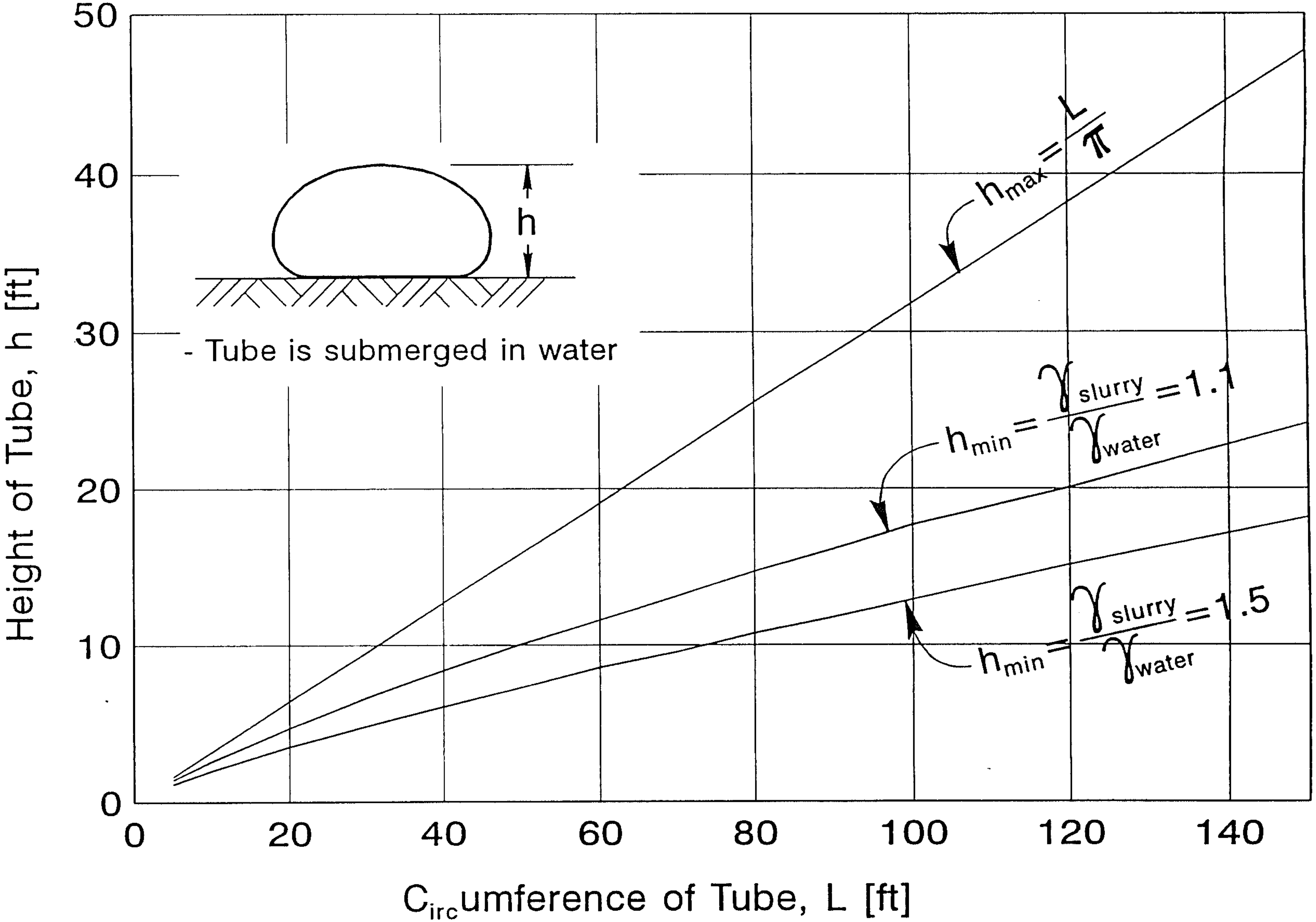


Figure 12. Extreme values of feasible heights of tube (Tube is submerged in water)

has negligible effects on h_{min}. However, full submergence (Figure 12) produces some limited effects on the minimum height. Also, h_{min} for the submerged tube is higher than for the non-submerged one. This is a result of reduction in effective stresses within the slurry as the tube becomes submerged. Reduced slurry stresses allow the tube to maintain a cross section that is close to a circle.

5.0 DESIGN CONSIDERATIONS

5.1 Geosynthetic Strength

The analysis in Chapter 2.0 renders the circumferential and axial force in the geosynthetic at working load conditions. However, to select a geosynthetic possessing adequate ultimate strength, safety factors should be applied to either calculated force. Current practice utilizes partial safety factors (e.g., Koerner, 1994). It is recommended to use the following partial safety factors:

$$T_{ult} = T_{work} \cdot (F_{s-id} \cdot F_{s-cd} \cdot F_{s-bd} \cdot F_{s-cr} \cdot F_{s-ss}) \quad \ldots \ldots \quad (12)$$

where:

T_{work}=the calculated tensile force in the geosynthetic at working load conditions, either in the circumferential direction ($T_{work}=T$) or in the axial direction ($T_{work}=T_{axial}$).

F_{s-ss}=factor of safety for seam strength. Seam efficiency may be quite low for high-strength woven geotextiles. A minimum preliminary value of *2.0* is recommended. The exact value should be determined using the test specified in ASTM D 4884-90 (Standard Test Method for Seam Strength of Sewn Geotextiles); i.e., this test provides the seam efficiency and $F_{s\text{-}ss}$ is, by definition, equal to 1/(seam efficiency).

$F_{s\text{-}id}$=factor of safety for installation damage. In the context of tubes, this factor refers to an accidental increase of pumping pressure. Such an increase is possible since accurate control of the pressure in the field is quite difficult to maintain. This increase may cause local rupture of the seam or of the geosynthetic in the vicinity of the seam. A preliminary minimal value of $F_{s\text{-}id}=1.3$ is recommended.

$F_{s\text{-}cd}$=factor of safety for chemical degradation. For a typical slurry, most geosynthetics are inert. To verify whether a slurry may cause damage, the test specified in ASTM D 5322-92 (Standard Practice for Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids) can be used as a guidance. However, to make the test meaningful, the actual slurry should be used. Furthermore, chemical degradation can be caused externally by a direct exposure to the sun (ultraviolet radiation, UV). To assess the tendency for such degradation, the test procedure specified in ASTM D 4355-92 (Standard Test Method for Deterioration of Geotextiles from Exposure to Ultraviolet Light and Water), can be used. Assuming that the geosynthetic is indeed inert and that the strength of the portions exposed to the sun is needed only during construction (and shortly after as the slurry solidifies), a minimum preliminary value of $F_{s\text{-}cd}=1.0$ is recommended. It should be pointed out that most geosynthetics contain carbon black and therefore, deteriorate slowly (typically years) when exposed to UV.

$F_{s\text{-}bd}$=factor of safety for biological degradation. Such degradation does not seem to be a problem in most cases where tubes are used and therefore, a preliminary value of $F_{s\text{-}bd}=1.0$ is recommended. However, this factor is left as part of Equation 12 to allow for its inclusion, if deemed necessary.

$F_{s\text{-}cr}$=factor of safety of creep. It signifies the require reduction of the ultimate strength so that at the end of the designed life of the structure, the deformations will be tolerable. The creep behavior of a geosynthetic can be determined using the test specified in ASTM D 5262-92 (Standard Test Method for Evaluating the Unconfined Tension Creep Behavior of Geosynthetics). However, this factor should be evaluated in the context of tubes. That is, maximum tensile force in the geosynthetic will be mobilized during pumping. After pumping, as the slurry solidifies, this force relaxes. Consequently, this maximum force will exist over a short period of time and therefore, a relatively small creep safety factor can be assigned. Its value must assure that the *tensile creep rupture strength* (see ASTM D 5263-92 for definition) will be larger than T_{work} within the time this force exists (i.e., during pumping and shortly after, as the excess pore water pressure dissipates and the slurry solidifies). It is recommended to use a minimum preliminary value of $F_{s\text{-}cr}=1.5$.

T_{ult}=the ultimate strength of the required geosynthetic. Note that its value should be in the circumferential direction if $T_{work}=T$ is used in Equation 12. If $T_{work}=T_{axial}$ is used, then T_{ult} is in the axial direction. A geosynthetic possessing, at least, these ultimate strengths in its warp and fill directions, with correspondence to the circumferential and axial directions, should be specified. The ultimate strength should correspond to the test specified in ASTM D 4595-94 (Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method).

5.2 Geosynthetic Retention of Solid Particles

Typically, the geosynthetic encapsulating the slurry has to function also as a filter. That is, allow the fluid transporting the solids into the tube to drain out while retaining the solid particles (i.e., perform as a 'cheese cloth'). As is the usual case with filters, the geosynthetic must possess two required properties that are opposing each other: be pervious and simultaneously, have a 'perfect' retention of solids. This perfect retention is particularly important in case contaminated soil is to be contained by the tube.

Using the geosynthetic to retain the solid particles in the slurry necessitates compatibility between it and the solids in the slurry. Using ASTM D 4751-93 (Standard Test Method for Determining Apparent Opening Size of a Geotextile) gives the apparent opening size, AOS, of the geosynthetic. AOS (or O_{95}) indicates the approximate largest solid particle that would effectively pass through the geosynthetic. Koerner (1994) provides an instructive table showing different design methods to assure the retention of a soil having a particular grain size distribution considering a given AOS. The method recommended here was developed by Task Force #25, AASHTO, and published in 1991:

1. For soil with ≤ 50% passing sieve No. 200: $O_{95} < 0.59$ mm (i.e., AOS ≥ sieve No. 30)

2. For soil with > 50% passing sieve No. 200: $O_{95} < 0.30$ mm (i.e., AOS ≥ sieve No. 50)

Consequently, upon using conventional test to determine the distribution of grain size of the slurry, one can specify the maximum allowed AOS of a geosynthetic. It should be noted that when the slurry is comprised of clayey soils, experience indicates (Leshchinsky, 1992) the geosynthetic openings tend to stop the passage of particles rapidly while allowing for water to seep clean outside. In case of contaminated slurry, however, the AOS criteria may have to be modified to assure a truly perfect retention. Such modification can be done through experiments simulating the in-situ conditions.

Using the on-site slurry, one can evaluate whether the selected geosynthetic will not clog. This performance feature can be determined using ASTM D 5101-90 (Standard Test Method for Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio). Typically, clogging should not be a problem if the AOS criteria was utilized in selecting a geosynthetic. If, however, the slurry may create a biological activity on the geosynthetic, the clogging potential then can be evaluated using ASTM D 1987-91 (Standard Test Method for Biological Clogging of Geotextile or Soil/Geotextile Filters). Biological activity is typically a long-term concern whereas the filtration capacity in a tube is usually a short term (a few months) issue.

It is quite possible that the conflicting requirements of 'perfect' particles retention and high permeability, combined with a required high-strength material, will result in a geotextile that is not available in the market. In this case, a nonwoven geotextile can be used as a liner to retain the fine particle. The outside geosynthetic can then be a high-strength woven (and very pervious) geotextile. This combination will produce an acceptable encapsulating material.

5.3 Consolidated Height of Tube

After the pumping and as the slurry consolidates (i.e., solidifies), the height of the tube drops while its maximum width increases very little. The drop in height can be very significant, especially when fine soil slurry is pumped in. The following approximate procedure allows for an estimate of the average drop in height once a certain density of the fill material is achieved.

Assuming the solidified slurry is fully saturated (*S*=100%) and using basic volume-weight relationships, it can be shown that:

$$\omega_o = \frac{G_s - \dfrac{\gamma_{slurry}}{\gamma_w}}{G_s(\dfrac{\gamma_{slurry}}{\gamma_w} - 1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

and

$$\omega_f = \frac{G_s - \dfrac{\gamma_{soil}}{\gamma_w}}{G_s(\dfrac{\gamma_{soil}}{\gamma_w} - 1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

where ω_0 and ω_f are the initial and final water content of the fill material, respectively; G_s is the specific gravity of solids (constant for same soil particles, regardless of change in water content); γ_{soil}, γ_{slurry} and γ_w are the unit weights of the soil (solidified slurry), slurry and water, respectively.

Assuming the consolidating material is moving only downwards (i.e., one-dimensional movement; negligible lateral movement) and making use of the relationship $[\Delta e/(1+e_0)]=\Delta h/h_0$, the following equation is obtained:

$$\frac{\Delta h}{h_o} = \frac{G_s\,(\omega_o - \omega_f)}{1 + \omega_o G_s} \quad \text{(15)}$$

where Δh and h_0 are the decrease in height of tube and initial height of tube, respectively.

Combining Equations 13, 14 and 15, one can estimate the drop in the height of the tube as the material inside densifies. Figure 13 illustrates the result of combining these equations, assuming G_s=2.70. Note, for example, that when a slurry having $(\gamma_{slurry}/\gamma_w)=1.1$ consolidates to $(\gamma_{soil}/\gamma_w)=1.2$ (i.e., 9% increase in density), the resulted decrease in height is about 50%. Experience indicates (e.g., Leshchinsky, 1992) that when fine grain material is pumped in, the tube will drop about 50% in height within about a month. At this stage, a solid soil is formed over which a person can walk. If the objective is to form a tube of a certain desired height, than additional slurry can be pumped in (GeoCoPS can handle two slurry densities inside the tube). This process can be repeated until the final desired height is attained. Alternatively, pumping sand (or soil with more than 50% of the particles greater than sieve No. 200) will result in final tube dimensions acceptable typically after only one pumping.

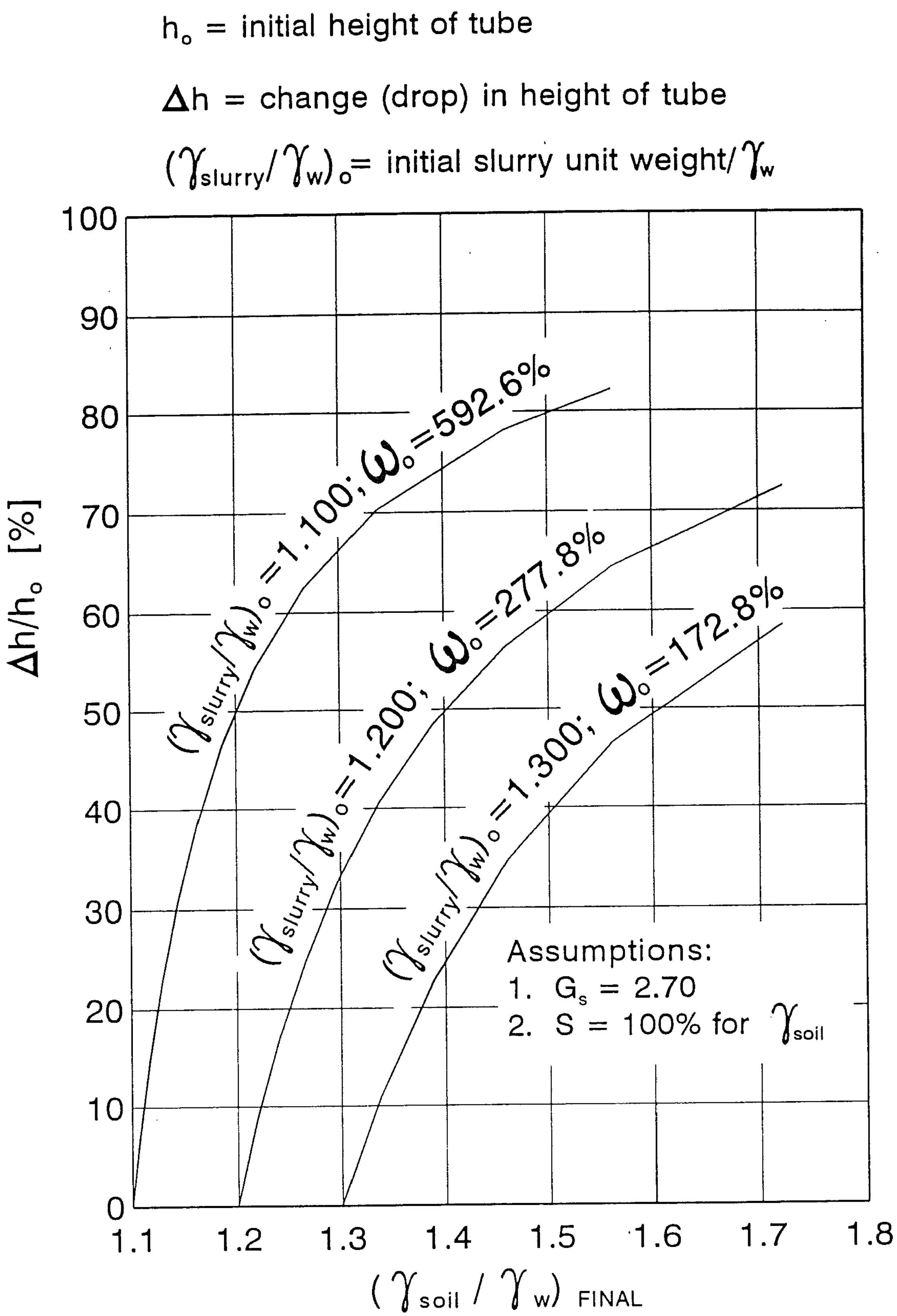


Figure 13. Drop in height of tube as function of density of soil

6.0 EXAMPLES USING GeoCoPS

Figure 14 shows the notation used in GeoCoPS. As seen, two different slurries can be specified. Also, outside liquid (typically water) may be present, partially or fully submerging the tube. Figure 15 illustrates the options available in GeoCoPS. While in the program the user can invoke the 'help' command. In response, either a concise descriptive text or a graphical illustration will appear.

The following pages in this chapter are direct printout of GeoCoPS resulting from the run of three different example problems. Example 1 utilizes the option to find the geometry of the tube and the pumping pressure for given circumference L and geosynthetic ultimate strength, T_{ult}, in the circumferential direction. Two slurry densities are specified; the outside water is 5 feet high, 2 feet lower than the bottom (and heavier) slurry layer. Note that although the circumference was specified as 80.0 feet (signifying, for example, 5 geotextile sheets, each having effective width of 16 feet, sewn together), the results converged to a circumference of 80.7 feet. This is well within the allowable numerical tolerance set in GeoCoPS (refer to chapter 2 to realize that a numerical process of finite accuracy must be utilized). The printout of results and Figure 16 show that the pumping pressure is only 0.5 *psi*. Note that the cross sectional area of each of the two slurries is also printed. This area signifies the volume of slurry per foot length of the tube. Hence, for a given tube length its 'storage' capacity can be evaluated. Also note that the required geosynthetic strength in the axial direction is quite high (about 77% of the circumferential one) implying that for this problem, a geosynthetic with an isotropic

Restrictions:

1. Density of upper slurry layer is less than or equal to that of lower.
2. Density of outside upper liquid is less than or equal to that of lower fluid.
3. Density of either lower or upper liquid is less than or equal to that of upper slurry layer.

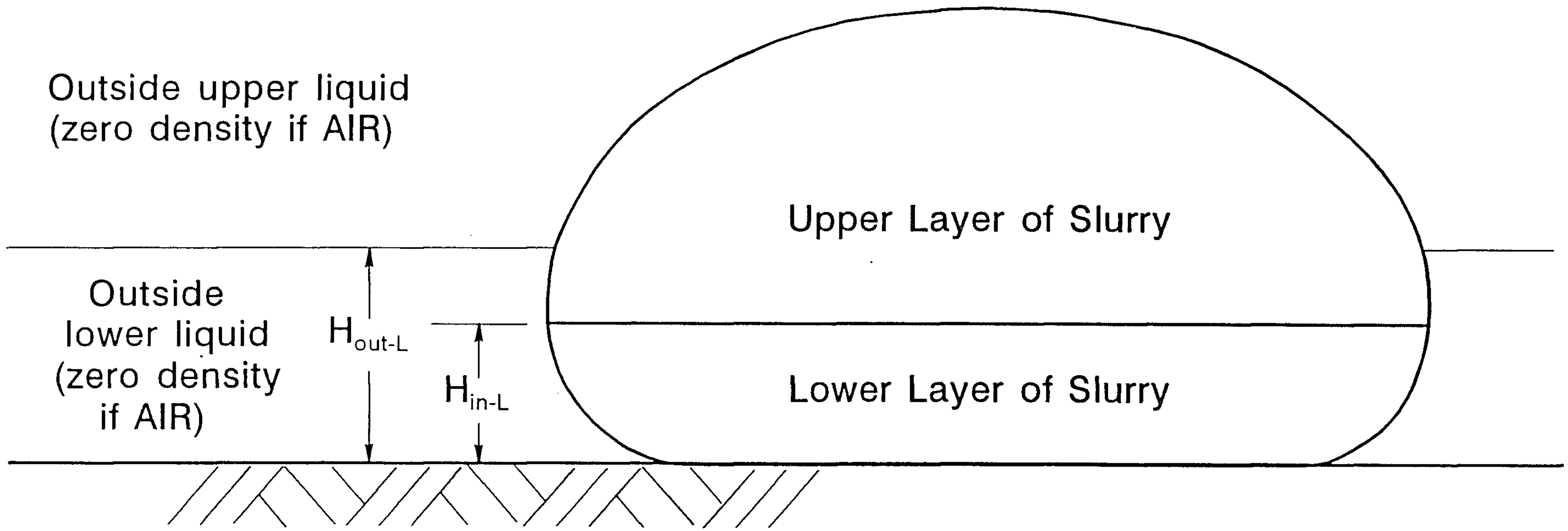


Figure 14. Notation used in GeoCoPS

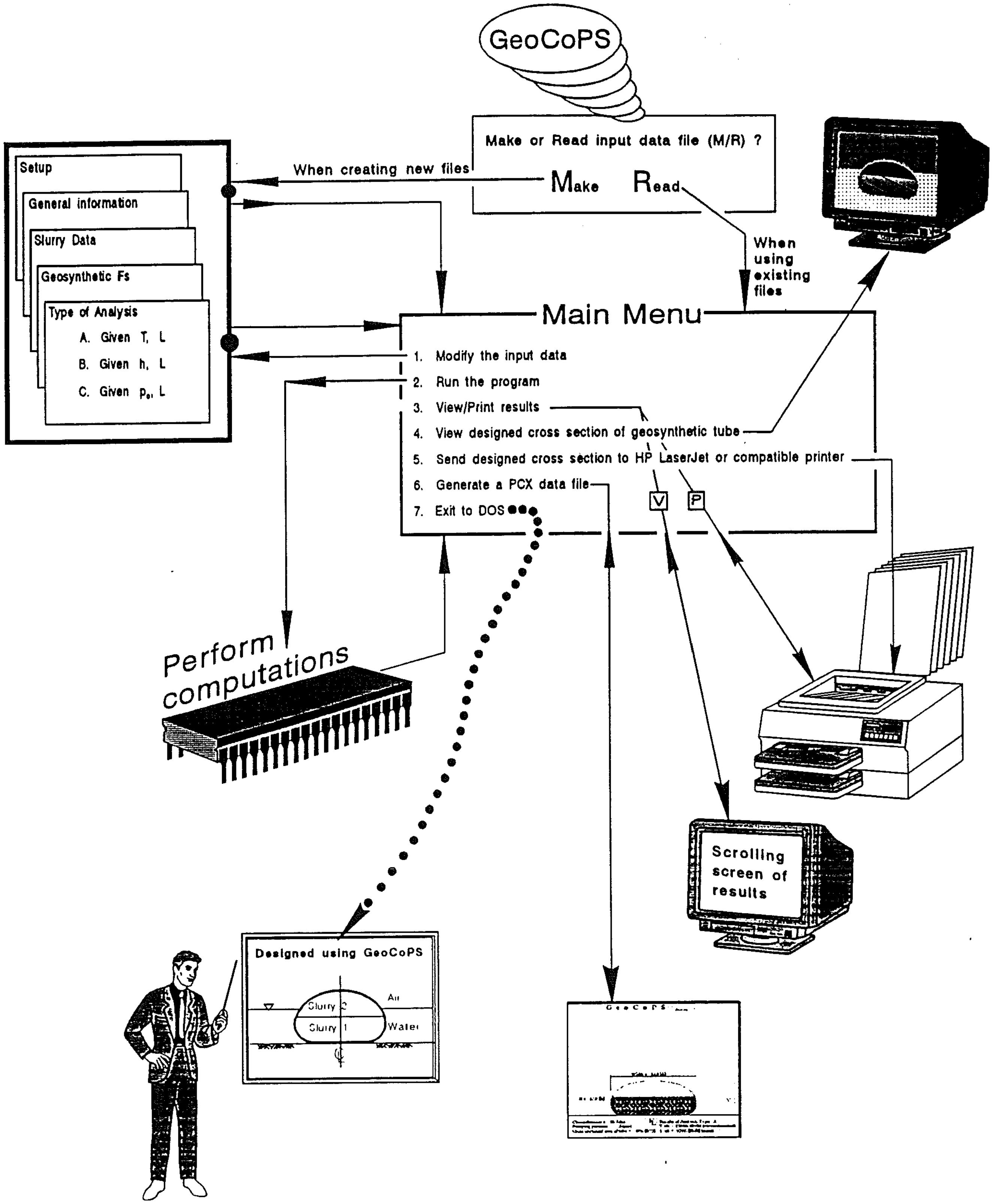


Figure 15. Schematic diagram showing options in GeoCoPS

strength (i.e., a fabric having the same strength in its warp and fill direction) will likely be the most practical to specify.

Example 2 is for a case where the circumference and desired height of the tube are given as 30.0 and 8.0 feet, respectively; the results, however, converged to numerically acceptable closeness of 30.6 and 7.9 feet. A uniform slurry and an unsubmerged tube are considered. See Figure 17 for the calculated cross section. Note that the required axial strength is about 58% of the circumferential one. Also, the required circumferential strength is rather large. Hence, there exists an economic incentive to specify an anisotropic geosynthetic; such geosynthetics are readily available. The required pumping head is about 7 feet (3.7 *psi*).

Finally, Example 3 is for a case where the circumference of the tube and the pumping pressure are given as 16.0 feet and 5.2 *psi*; the results converged to 16.2 feet and 5.2 *psi*. As in Example 2, one type of slurry and no water outside the tube were specified; however, the slurry density has been increased. See Figure 18 for the calculated cross section view. Once again, the results indicate that an anisotropic geosynthetic for this problem is possibly most economical. Comparing Examples 2 and 3, one sees that cutting the circumference by about 50% will decrease the area of the tube (i.e., storage capacity) by about 70%. It should be pointed out that in running the analysis option utilized in Example 3, the user is always limited to one type of slurry and either total submergence in water or no submergence at all.

G e o C o P S

Version 1.0

Geosynthetic Confined Pressurized Slurry

Project Title: Example 1

Project Number: N/A

Project Designer: N/A

Description: Given the circumference of the tube and the geosynthetic strength. Find the geometry of the tube as well as the pumping pressure.

Input File Name: EXAMPLE1.IN
Output File Name: EXAMPLE1.OUT
Date: 04/26/95
Time: 12:11:23

Input data file: EXAMPLE1.IN Date printed: 04/26/95 Time printed: 12:11:23

G e o C o P S Version 1.0
Geosynthetic Confined Pressurized Slurry

```
roject title:       Example 1
roject No.:         N/A
roject designer:    N/A
roject description: Given the circumference of the tube
                    and the geosynthetic strength. Find
                    the geometry of the tube as well as
                    the pumping pressure.


                              D A T A
   Density of Slurry/Density of Water: 1. Lower layer..     1.3
                                       2. Upper layer..     1.1
   Density of outside liquid/Density of Water:
                                       1. Lower layer..     1.0
                                       2. Upper layer..      .0
   Specified height of lower layer of slurry, Hin-L....     7.0 ft
   Specified height of outside lower layer of liquid,
                  Hout-L...............................     5.0 ft
   Specified safety factors for geosynthetic:
                 1. Installation damage, Fs-id.........  1.3
                 2. Chemical degradation, Fs-ch........  1.0
                 3. Biological degradation, Fs-bd......  1.0
                 4. Creep, Fs-cr.......................  1.5
                 5. Seam strength, Fs-ss...............  2.0
   Requested type of analysis:  'A' - solve the problem for a
   circumference of     80.0 ft  and ULTIMATE strength
      of geosynthetic of   12000. lb/ft

                             R E S U L T S

   Results are for a solution converging to a circumference of tube
       of    80.7 ft  and ULTIMATE geosynthetic strength of  12000. lb/ft
   Geosynthetic in CIRCUMFERENTIAL direction:
        Tensile force at WORKING conditions...........  3077. lb/ft
        Required ULTIMATE strength.................... 12000. lb/ft
   Geosynthetic in AXIAL direction:
        Tensile force at WORKING conditions...........  2384. lb/ft
        Required ULTIMATE strength....................  9297. lb/ft
   Maximum height of tube, H..........................   12.9 ft
   Maximum width of tube, W...........................   34.0 ft
                 (at height     4.5 ft from base)
   Ratio H/W..........................................   .381
   Width of base of tube..............................   25.3 ft
   Cross sectional area of lower layer of slurry.......  228.8 ft^2
   Cross sectional area of upper layer of slurry.......  146.7 ft^2
   Net pumping pressure within tube at inlet..........      .5 psi
```

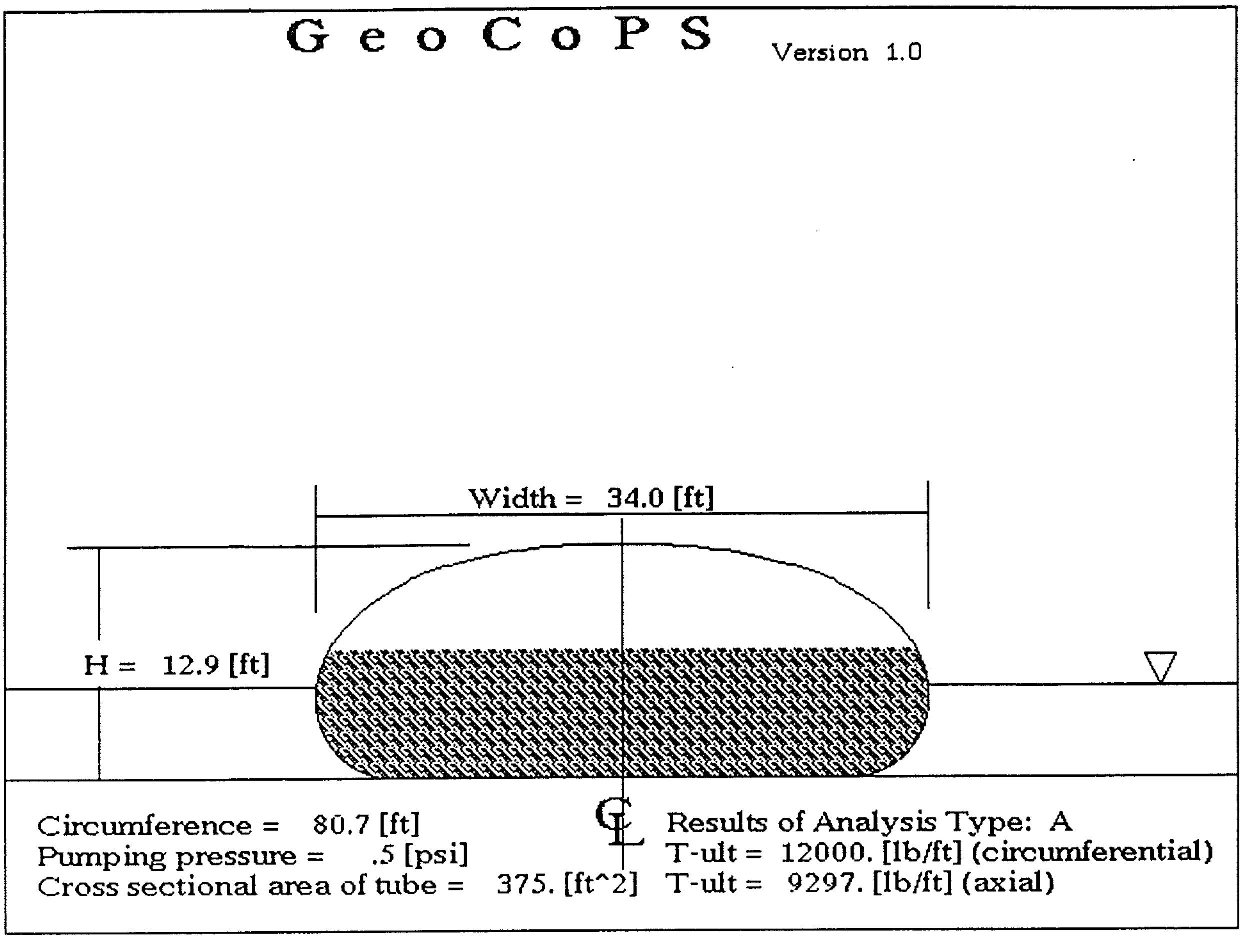


Figure 16. Cross sectional view: Example 1.

G e o C o P S

Version 1.0

Geosynthetic Confined Pressurized Slurry

Project Title: Example 2

Project Number: N/A

Project Designer: N/A

Description: Given the circumference of the tube and its desired height. Find the geometry of the tube, the pumping pressure and the required strength of the geosynthetic.

Input File Name: EXAMPLE2.IN
Output File Name: EXAMPLE2.OUT
Date: 04/26/95
Time: 12:36:24

Input data file: EXAMPLE2.IN Date printed: 04/26/95 Time printed: 12:36:24

G e o C o P S Version 1.0
Geosynthetic Confined Pressurized Slurry

```
roject title:       Example 2
roject No.:         N/A
roject designer:    N/A
roject description: Given the circumference of the tube
                    and its desired height. Find the
                    geometry of the tube, the pumping
                    pressure and the required strength
                    of the geosynthetic.

                            D A T A
Density of Slurry/Density of Water: 1. Lower layer..     1.2
                                    2. Upper layer..     1.2
Density of outside liquid/Density of Water:
                                    1. Lower layer..      .0
                                    2. Upper layer..      .0
Specified height of lower layer of slurry, Hin-L....    10.0 ft
Specified height of outside lower layer of liquid,
               Hout-L...............................      .0 ft
Specified safety factors for geosynthetic:
              1. Installation damage, Fs-id.........  1.3
              2. Chemical degradation, Fs-ch........  1.0
              3. Biological degradation, Fs-bd......  1.0
              4. Creep, Fs-cr.......................  1.5
              5. Seam strength, Fs-ss...............  2.0
Requested type of analysis:  'B' - solve the problem for a
circumference of     30.0 ft  and maximum designed height
of tube of      8.0 ft

                         R E S U L T S

Results are for a solution converging to a circumference of tube
       of    30.6 ft  and maximum tube height of     7.9 ft
Geosynthetic in CIRCUMFERENTIAL direction:
     Tensile force at WORKING conditions............  3375. lb/ft
     Required ULTIMATE strength..................... 13162. lb/ft
Geosynthetic in AXIAL direction:
     Tensile force at WORKING conditions............  1960. lb/ft
     Required ULTIMATE strength.....................  7643. lb/ft
Maximum height of tube, H...........................    7.9 ft
Maximum width of tube, W............................   10.9 ft
              (at height     3.3 ft from base)
Ratio H/W...........................................   .731
Width of base of tube...............................    4.7 ft
Cross sectional area of lower layer of slurry.......   71.0 ft^2
Cross sectional area of upper layer of slurry.......     .0 ft^2
Net pumping pressure within tube at inlet...........    3.7 psi
```

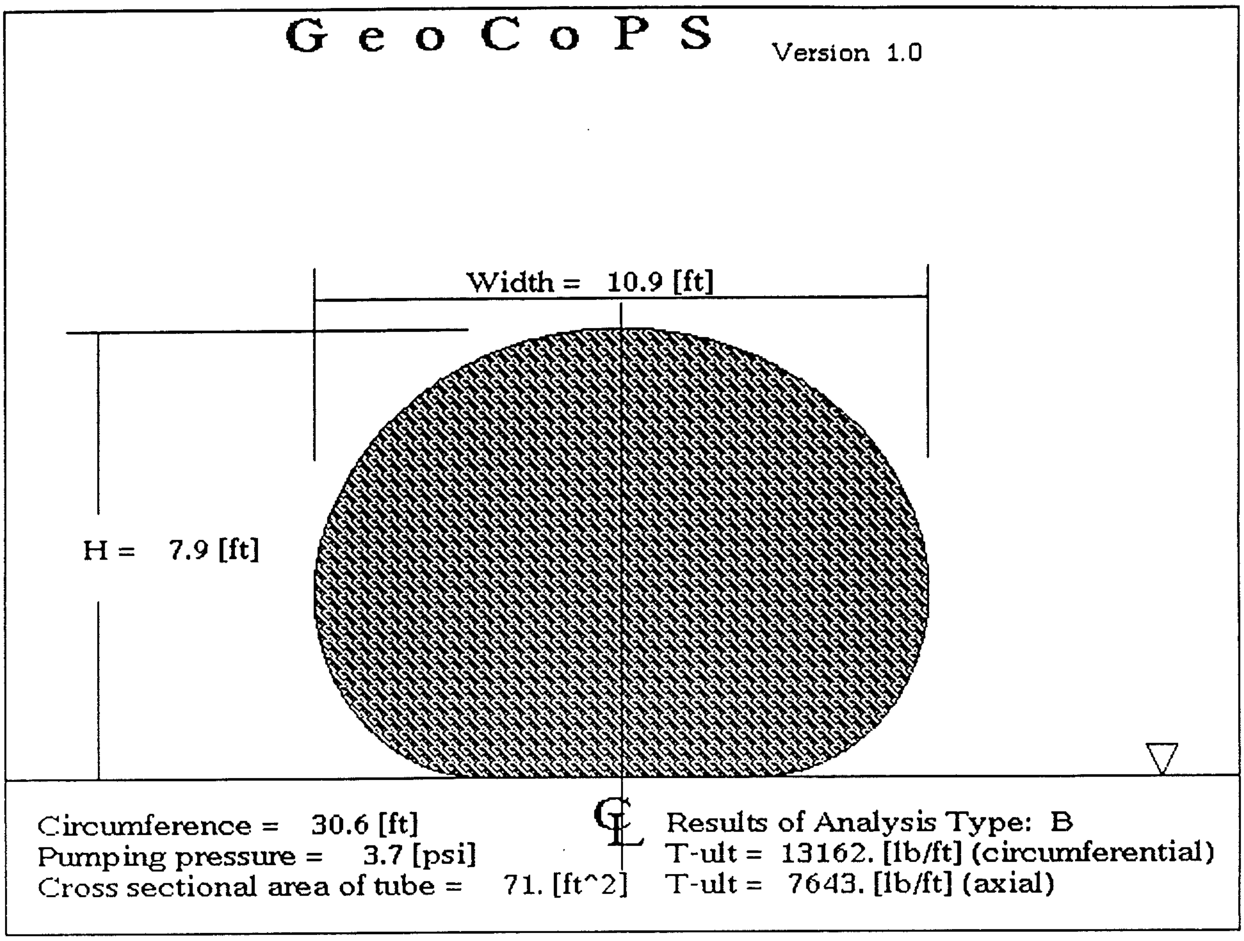


Figure 17. Cross sectional view: Example 2.

G e o C o P S

Version 1.0

Geosynthetic Confined Pressurized Slurry

Project Title: Example 3

Project Number: N/A

Project Designer: N/A

Description: Given the circumference of the tube and the pumping pressure. Find the geometry of the tube and the required geosynthetic strength in the circumferential and axial dir.

Input File Name: EXAMPLE3.IN
Output File Name: EXAMPLE3.OUT
Date: 04/26/95
Time: 18:04:05

Input data file: EXAMPLE3.IN Date printed: 04/26/95 Time printed: 18:04:05

G e o C o P S Version 1.0
Geosynthetic Confined Pressurized Slurry

roject title: Example 3
roject No.: N/A
roject designer: N/A
roject description: Given the circumference of the tube and the pumping pressure. Find the geometry of the tube and the required geosynthetic strength in the circumferential and axial dir.

D A T A

```
Density of Slurry/Density of Water..................      1.4
Density of outside liquid/Density of Water..........       .0
Specified height of lower layer of slurry, Hin-L....      5.0 ft
Specified height of outside lower layer of liquid,
             Hout-L.................................       .0 ft
Specified safety factors for geosynthetic:
             1. Installation damage, Fs-id.........   1.3
             2. Chemical degradation, Fs-ch........   1.0
             3. Biological degradation, Fs-bd......   1.0
             4. Creep, Fs-cr.......................   1.5
             5. Seam strength, Fs-ss...............   2.0
Requested type of analysis:  'C' - solve the problem for a
circumference of     16.0 ft  and net pumping pressure
of      5.2 psi  at inlet.
```

R E S U L T S

```
Results are for a solution converging to a circumference of tube
       of   16.2 ft  and pumping pressure of     5.2 psi
Geosynthetic in CIRCUMFERENTIAL direction:
     Tensile force at WORKING conditions............  2185. lb/ft
     Required ULTIMATE strength.....................  8522. lb/ft
Geosynthetic in AXIAL direction:
     Tensile force at WORKING conditions............  1214. lb/ft
     Required ULTIMATE strength.....................  4735. lb/ft
Maximum height of tube, H...........................    4.6 ft
Maximum width of tube, W............................    5.5 ft
             (at height     2.1 ft from base)
Ratio H/W...........................................   .839
Width of base of tube...............................    1.6 ft
Cross sectional area of slurry......................   20.4 ft^2
```

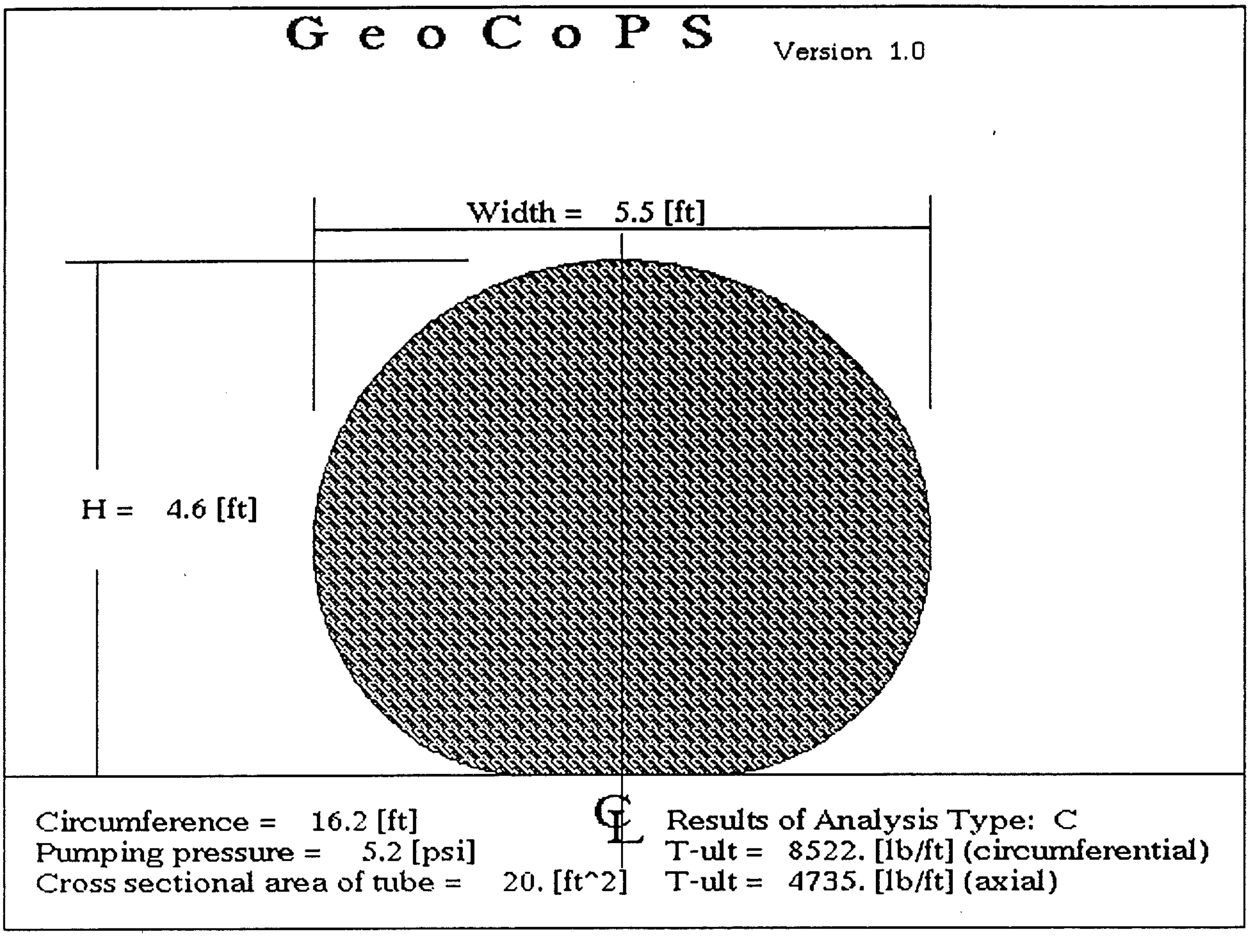


Figure 18. Cross sectional view: Example 3.

7.0 REFERENCES

Bogossian, F., Smith, R.T., Vertematti, J.C. and Yazbek, O. 1982. Continuous retaining dikes by means of geotextiles. *Proceedings of the 2nd International Conference on Geotextiles*, IFAI, Las Vegas. Vol. 1, 211-216.

Carrol, R.P. 1994. Submerged geotextile flexible forms using noncircular cylindrical shapes. *Geotechnical Fabrics Report*, IFAI. 12(8). 4-15.

Kazimierowicz, K. 1994. Simple analysis of deformation of sand-sausages. *Proceedings of the 5th International Conference on Geotextile, Geomembranes and Related Products*, Singapore. 775-778.

Koerner, R. M. 1994. Designing with geosynthetics. *Prentice-Hall Inc.*, Englewood Cliffs, New Jersy 07632.

Leshchinsky, D. 1992. Issues in geosynthetic-reinforced soil. Keynote paper in *Proceedings of the International Symposium on Earth Reinforcement Practice*, Kyushu, Japan. Published by Balkema, Rotterdam. 871-897.

Liu, G.S. 1981. Design criteria of sand sausages for beach defences. *The 19th Congress of the International Association for Hydraulic Research*, New Delhi, India. Subject B(b), Paper No. 6. 123-131.

Ockels, R. 1991. Innovative hydraulic engineering with geosynthetics. *Geosynthetics World*. 2(4). 26-27.

Perrier, H. 1986. Use of soil-filled synthetic pillows for erosion protection. *Proceedings* *of the 3rd International Conference on Geotextiles*, Vienna. Vol. 4, 1115-1119.

Pilarczyk, K. W. 1994. Novel systems in coastal engineering: geotextile systems and other methods, an overview. Road and Hydraulic Engineering Division of the Rijkswaterstaat, P. O. Box 5044, 2600 GA Delft, The Netherlands.

Silvester, R. 1986. Use of grout-filled sausages in coastal structures. *Journal of Waterway Port Costal and Ocean Engineering*, ASCE. 112(1). 95-114.

Sprague, C. J. 1993. Dredged material filled fabric tubes. Report submitted to the Construction Products Division, Nicolon Corporation. Project No. CJS-92-008.