FINAL DESIGN CALCULATION PACKAGE ON-SITE DISPOSAL FACILITY

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Fernald Environmental Management Project
Fernald, Ohio

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Under

Fluor Fernald, Inc.
Subcontract 95PS005028

COMPUTATION COVER SHEET

3496

SUBJECT OF COMPUTATIONS BIOINTRUSION BARRIER RE-EVALUATION

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Record of Revision (Number and initial all revisions)

Rev. No.	Reason	Date	By	Checked	Approval
A					
1	FOR RESPONSE TO OEPA COMMENTS	02/14/01	DGP	CDC	JFB

Written by: Ganesh Gopalakrishnan (GG) Date: 16 Dec 00 Reviewed by: John F. Beech (JFB) Date:

Client: Fluor Fernald Project: Re-evaluation - Biointrusion Barrier Project/Proposal No.: GQ1030 Task No.: 14

RE-EVALUATION OF BIOINTRUSION BARRIER

PURPOSE

The purpose of this calculation package is to present the calculations for the re-evaluation of the rock requirements for the biointrusion layer for the final cover system of the Onsite Disposal Facility. This calculation presents revisions to Section 11.6 titled "Final Cover System Biointrusion Barrier Design" of the *Final Design Calculation Package for On-Site Disposal Facility, Revision 0, dated May 1997* (hereinafter referred as Revision 0 Final Design Calculations), prepared by GeoSyntec Consultants (GeoSyntec).

This revised calculation is performed because of the reasons outlined below.

- Additional tests to evaluate the quality of rock available from local quarries was recently performed including rock from quarries not previously considered. Rock quality scores for dumped rock fill from 5 local quarries were established from the results of the testing program.

- Additional information from the technical literature on internal friction angle of rock fill is available, which was not considered in the original calculations. This information defines internal friction angles for rock under low confining pressures, which are representative of the confining pressures the biointrusion barrier is subjected.

- An overly conservative interpretation of the UMTRA design approach was used in the original design calculations. This approach oversized the rock based on the ratio of a score of 80 percent to that of the rock quality score of the actual source (e.g., 80/50 or 1.6 for a material with a rock quality of score of 50 percent) instead of the difference (e.g., 80-50, or increasing the diameter by 30 percent or a factor of 1.3)

Based on the revised design of biointrusion barrier, the choke stone is also resized.

CALCULATIONS

Calculations procedures adopted herein are in general accordance with the methodology adopted in the calculations performed in the Revision 0 Final Design Calculations. The general procedure is described below.

- **Step 1:** Laboratory testing results for rock quality from five potential local quarries were obtained. Attachment 1 provides the summary of testing results.

All these stones meet the Ohio DOT Type D dumped rock fill with a D_{50} = 6 inches. The following properties from these tables are utilized in the calculations.

- Split Tensile Strength;
- Bulk Specific Gravity; and
- Overall Weighted Score.

Calculations are performed for rock from two quarries namely LITERS QUARRY and MELVIN STONE QUARRY because they had the lowest rock quality score of the five quarries tested. The other quarries will be acceptable if one or both of these quarries are acceptable.

AI DGP 02/14/01

The calculation was performed using a peak discharge of 4.33 cfs for the 2000-yr storm event obtained from Rev. 0 Final Design Package calculation Final cover System Erosion Resistence. The 2000-year event is the applicable storm as defined in Section 2.8.4, PART A, Bullet 2 of the PHase III Rev. 0 Design Criteria Package.

- **Step 2:** Manning's Roughness Coefficient of Riprap with D_{50} = 6 inches is computed using the procedure described in Attachment 2.

- **Step 3:** The maximum flow per unit width in the center of the erosion gully is calculated as shown in Attachment 3. ~~The peak discharge (Q) was calculated earlier based on hydrology procedures in Revision 0 Final Design Calculations. Q=4.33 cfs calculated earlier is utilized.~~ The depth of flow is calculated using an iterative solution procedure for Manning's equation on a computer spreadsheet. Based on this calculation, the Maximum flow per unit width for the 2000-year storm in the erosion gully (~~qm~~ q_{MAX}) is 2.50 cfs/ft. AI DGP 02/14/01

- **Step 4**: Attachment 4 provides the calculation for friction angle of the rocks from the above two quarries, based on Split Tensile Strength and Effective Normal Stress. The calculated friction angles are:
  - ϕ_{LITERS} = 48 degrees
  - ϕ_{MELVIN} = 45 degrees

- **Step 5:** Attachment 5 provides the calculation of "Required D_{50}" based on the Stephenson Method. The maximum flow per unit width calculated in Step 3, and friction angle calculated in Step 4 is utilized for this calculation.

- **Step 6:** Attachment 6 provides the calculation of "Required Oversized D_{50}" based on the "Overall Weighted Score" for the rocks and the UMTRA procedure. Based on the these calculations:
  - Required Oversized D_{50} for LITERS QUARRY = 5.64 inches; and
  - Required Oversized D_{50} for MELVIN STONE QUARRY = 6.83 inches

Since, it was assumed that Ohio DOT Type D dumped rock fill with a D_{50} = 6 inches will be used, MELVIN STONE QUARRY stones will <u>not</u> meet the oversizing requirement. Therefore, further calculations are performed for the LITERS QUARRY stone.

- **Step 7:** Attachment 7 provides the calculations to verify whether riprap with $D_{50} = 6$ inches meets the erosion criteria based on the Hartung and Scheuerlein Method. The "allowable flow per unit width" for riprap with $D_{50} = 6$ inches calculated using the Hartung and Scheuerlein Method is ~~less~~ than the "~~expected~~ maximum flow per unit width" calculated in Step 3. Therefore, based on this method, riprap with $D_{50} = 6$ inches is acceptable for the biointrusion barrier. greater Δ1 DGP 02/1

- **Step 8:** Attachment 8 provides the calculations for evaluating the choke stone layer considering the revised biointrusion barrier stone. Based on the calculations performed, the Ohio DOT Number 57 stone is acceptable as a choke stone layer.

- **Step 9:** Attachment 9 provides a list of references.

CONCLUSIONS

- Ohio DOT Type D Dumped Rock Fill can be used as a biointrusion barrier if it scores a minimum rock quality of 60 based on UMTRA technical approach.

- Ohio DOT Type D Dumped Rock Fill will meet the erosion resistance requirements for the final cover system.

- Ohio No. 57 Stone can be used for the choke stone if Ohio DOT Type D dumped rock fill is used for the biointrusion barrier.

- Granular filter material remains Ohio DOT Item 703.06

ATTACHMENT 1

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Source	Test	# Results	Average Results	Weighing Factor	Weighted Score
Liters Quarry	Bulk specific gravity (ASTM C295) (1)	2	2.63	12	76
	Absorption (ASTM C127) (1)	2	1.9	13	32
	Sulfate soundness (ASTM C88) (1)	2	6	4	74.1
	Schmidt Rebound Hammer (2)	20	53.24	11	68.9
	Los Angeles Abrasion (ASTM C131 or C535) (1)	2	26	1	0
	Splitting tensile (Brazilian disk) (ASTM D3967) (3)		1259.60	6	93.0
	Overall Weighted Score				62.6
New Point Stone Quarry	Bulk specific gravity (ASTM C295) (1)	4	2.669	12	83.8
	Absorption (ASTM C127) (1)	4	1.54	13	39.2
	Sulfate soundness (ASTM C88) (2)	1	4.8	4	81.0
	Schmidt Rebound Hammer (2)	50	59.96	11	79.9
	Los Angeles Abrasion (ASTM C131 or C535) (1)	3	27.4	1	0
	Splitting tensile (Brazilian disk) (ASTM D3967) (3)		1261.75	6	93.1
	Overall Weighted Score				69.7
Melvin Stone Quarry	Bulk specific gravity (ASTM C295) (1)	11	2.59	12	68
	Absorption (ASTM C127) (1)	5	2.16	13	26.8
	Sulfate soundness (ASTM C88) (1)	5	1.5	4	97.5
	Schmidt Rebound Hammer (2)	40	43.87	11	55.5
	Los Angeles Abrasion (ASTM C131 or C535) (1)	5	34.08	1	0
	Splitting tensile (Brazilian disk) (ASTM D3967) (3)		1094.58	6	84.7
	Overall Weighted Score				56.9

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Source	Test	# Results	Average Results	Weighing Factor	Weighted Score
Davon Highland Stone Quarry	Bulk specific gravity (ASTM C295) (1)	2	2.68	12	86
	Absorption (ASTM C127) (1)	1	1.1	13	48
	Sulfate soundness (ASTM C88) (1)	1	1.77	4	96.15
	Schmidt Rebound Hammer (2)	20	58.10	11	76.8
	Los Angeles Abrasion (ASTM C131 or C535) (1)	1	26.5	1	0
	Splitting tensile (Brazilian disk) (ASTM D3967) (3)		1284.51	6	94.2
	Overall Weighted Score				73.4
Davon Eagle Quarry	Bulk specific gravity (ASTM C295) (1)	2	2.66	12	82
	Absorption (ASTM C127) (1)	1	1.3	13	44
	Sulfate soundness (ASTM C88) (1)	1	1.83	4	95.85
	Schmidt Rebound Hammer (2)	20	57.18	11	75.3
	Los Angeles Abrasion (ASTM C131 or C535) (1)	1	22.2	1	15.6
	Splitting tensile (Brazilian disk) (ASTM D3967) (3)		1344.70	6	97.2
	Overall Weighted Score				71.6

(1) Data provided by quarries (Appendix).
(2) Testing performed by UC.
(3) Data extrapolated (Section).

ATTACHMENT 2

Written by: _____ Date: ___/___/___ (YY MM DD) Reviewed by: _____ Date: 00/12/15 (YY MM DD)

Client: _____ Project: _____ Project/Proposal No.: _____ Task No.: _____

CALCULATION OF MANNING'S N FOR RIPRAP

Manning's "n" value for riprap is estimated using the following equation [HRB, 1970]:

$$n = 0.0395 d_{50}^{\frac{1}{6}}$$

where: n = Manning's roughness coefficient; and
d_{50} = Median riprap diameter (ft).

$d_{50} = 6'' = 0.5$ ft

$$n = (0.0395)(d_{50})^{1/6}$$
$$= (0.0395)(0.5)^{1/6} = \underline{0.035}$$

HRB. 1970. *National Cooperative Highway Research Program Report 108: Tentative Design Procedure for Riprap-Lined Channels.* Washington, D.C.: Highway Research Board.

ATTACHMENT 3

10/36

Design/Check: Trapezoidal/Triangular Channel

Methodology: Manning's Equation

Project: FLUOR FERNALD

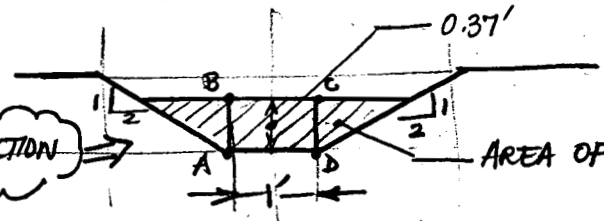
Task: **Bio-intrusion Barrier Re-evaluation**

Peak Discharge, Q_{max} =	4.33	cfs
Bottom Width, B =	1.00	ft
Left Side Slope, Z_1 =	2.00	horizontal :1 vertical
Right Side Slope, Z_2 =	2.00	horizontal :1 vertical
Manning's Roughness Coeff., n =	0.035	
Longitudinal Channel Slope, S_o =	0.1670	ft/ft

Depth of Flow Y ft	Area of Flow A ft^2	Wetted Perimeter P ft	Hydraulic Radius R=A/P ft	Average Velocity V ft/s	Discharge (Flow Rate) Q=AV ft^3/s	Avg. Tractive Stress τ_o lb/ft^2	Comments
0.01	0.01	1.04	0.01	0.79	0.01	0.10	
0.20	0.27	1.88	0.15	4.82	1.32	1.52	
0.38	0.68	2.71	0.25	6.89	4.67	2.60	
0.57	1.22	3.55	0.34	8.53	10.41	3.58	
0.76	1.90	4.38	0.43	9.97	18.95	4.52	
0.94	2.72	5.22	0.52	11.27	30.70	5.44	
1.13	3.68	6.05	0.61	12.49	46.01	6.34	
1.32	4.78	6.89	0.69	13.64	65.26	7.24	
1.50	6.02	7.72	0.78	14.74	88.78	8.13	
1.69	7.40	8.56	0.86	15.79	116.90	9.01	
1.88	8.92	9.39	0.95	16.81	149.94	9.90	
2.06	10.58	10.23	1.03	17.79	188.21	10.78	
2.25	12.38	11.06	1.12	18.75	232.01	11.66	
0.37	0.64	2.65	0.24	6.76	4.35	2.53	DESIGN Q

PEAK DISCHARGE IN GULLY (2000-YEAR) = 4.33 CFS
(ESTABLISHED FROM HYDROLOGY PROCEDURES)

ASSUMED GULLY CROSS-SECTION



AREA OF FLOW = 0.64 FT^2 = A

CONCENTRATED AREA OF FLOW = AREA(ABCD) = A_c = ✓
= (0.37)(1) = 0.37 FT^2

MAXIMUM FLOW PER UNIT WIDTH IN CENTER OF CHANNEL = $\left(\frac{A_c}{A}\right) Q = \left(\frac{0.37}{0.64}\right)(4.33) = 2.50$ CFS/FT ✓

ATTACHMENT 4

Written by: GG Date: 00/12/15 (YY/MM/DD) Reviewed by: _____ Date: 00/12/15 (YY/MM/DD)

Client: _____ Project: _____ Project/Proposal No.: _____ Task No.: _____

CALCULATION FOR FRICTION ANGLE OF MELVIN STONE

1. LOWEST TENSILE STRENGTH FOR STONE = 1,094 psi
2. BASED ON JAEGER AND COOK [1969] FOR ROCKS,

$$\frac{\text{UNCONFINED COMPRESSIVE STRENGTH } (q_u)}{\text{TENSILE STRENGTH } (q_t)} \sim 10$$

THEREFORE, $q_u = (10)(1{,}094) = \underline{10{,}940}$ psi

$= \underline{75}$ MPa

3. BASED ON TABLE PROVIDED IN TABLE 19.3 [TERZAGHI, ~~1966~~ 1996], FOR $q_u = 75$ MPa ROCKFILL GRADE = E

4. NORMAL STRESS IN THE BIO-INTRUSION BARRIER;

MINIMUM DEPTH = 2.75'

MAXIMUM DEPTH = 5.75'

DENSITY = 125 pcf

σ_n (max) = (2.75)(125) = 343.75 psf = 16.46 kPa

σ_n (min) = (5.75)(125) = 718.75 psf = 34.42 kPa

5. BASED ON FIGURE PROVIDED IN FIGURE 19.3 [TERZAGHI, ~~1966~~ 1996]

MAXIMUM VALUE OF ϕ FOR GRADE 'E' IS CHOSEN (INSTEAD OF EXTRAPOLATING OUTSIDE THE LIMIT FOR σ = 34.4 kPa OR 16.5 kPa)

$\phi = 45°$

Written by: GG Date: 00/12/15 Reviewed by: Date: 00/12/15

Client: Project: Project/Proposal No.: Task No.:

CALCULATION FOR FRICTION ANGLE OF LITERS STONE

1. LOWEST TENSILE STRENGTH FOR STONE = 1260 psi
2. BASED ON JAEGER AND COOK [1969] FOR ROCKS,

$$\frac{\text{UNCONFINED COMPRESSIVE STRENGTH } (q_u)}{\text{TENSILE STRENGTH } (q_t)} \sim 10$$

THEREFORE, $q_u = (10)(1{,}094) = 12{,}600$ psi

$= 87$ MPa

3. BASED ON TABLE PROVIDED IN TABLE 19.3 [TERZAGHI, ~~1966~~ 1996], FOR $q_u = 87$ MPa ROCKFILL GRADE = D

4. NORMAL STRESS IN THE BIO-INTRUSION BARRIER;

MINIMUM DEPTH = 2.75'

MAXIMUM DEPTH = 5.75'

DENSITY = 125 pcf

σ_n (max) = (2.75)(125) = 343.75 psf = 16.46 kPa

σ_n (min) = (5.75)(125) = 718.75 psf = 34.42 kPa

5. BASED ON FIGURE PROVIDED IN FIGURE 19.4 [TERZAGHI, ~~1966~~ 1996]

MAXIMUM VALUE OF ϕ FOR GRADE 'D' IS CHOSEN (INSTEAD OF EXTRAPOLATING OUTSIDE THE LIMIT FOR σ = 34.4 kPa or 16.5 kPa)

$\phi = 48°$

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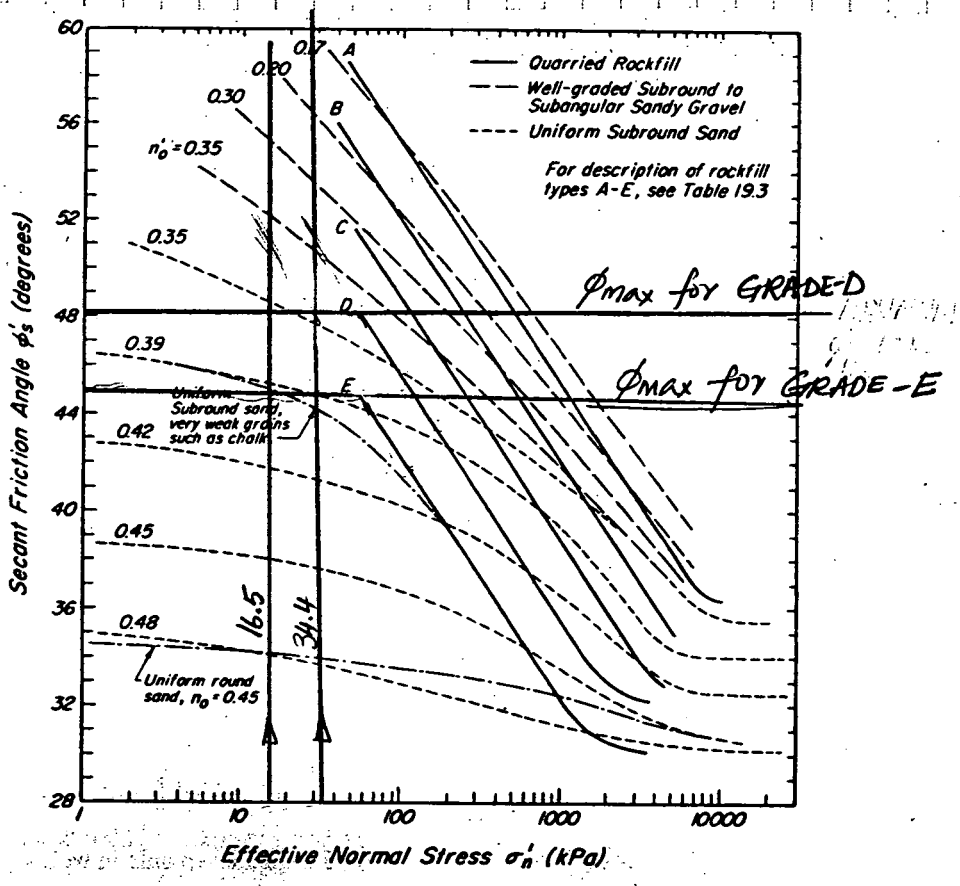

Figure 19.4 Values of secant friction angle for granular soils.

Table 19.3 Unconfined Compressive Strength of Particles for Rockfill Grades in Fig. 19.4

Rockfill Grade	Particle q_u (MPa)
A	≥220
B	165–220
C	125–165
D	85–125
E	≤85

Terzaghi, K., Peck, R.B., Mesri, G., "Soil Mechanics in Engineering Practice" 3rd ed., John Wiley & Sons, Inc., New York, 1996, 549p.

ATTACHMENT 5

Written by: GG Date: 00/12/15 (YY MM DD) Reviewed by: _____ Date: 00/12/16 (YY MM DD)

Client: _____ Project: _____ Project/Proposal No.: _____ Task No.: _____

8. STEPHENSON METHOD

The Stephenson Method [Abt et al., 1988] is used to evaluate the resistance of the biointrusion barrier against gully advancement, should a gully erode through the overlying topsoil, vegetative support, and gravel choke layers. This method is based on work by Olivier [1967] who studied flow over riprap on slopes, for the purpose of designing rockfill dams to be overtopped. This method is recommended by NRC [1990] for evaluating the erosion resistance of slopes greater than 10%.

The acceptable riprap mean particle diameter (D_{50}) to survive the design flow is calculated with the following equation [Abt et al., 1988]:

$$D_{50} = \left[\frac{q(\tan\theta)^{7/6} n_p^{1/6}}{C g^{1/2}\left[(1-n_p)(G_s-1)\cos\theta(\tan\phi - \tan\theta)\right]^{5/3}} \right]^{2/3}$$

Where:
- q = design flow per unit width
- θ = slope = 0.167 ft/ft (Section 5.)
- n_p = porosity of riprap
- C = empirical factor
- g = acceleration of gravity (32.2 ft/s^2)
- G_s = specific gravity of riprap
- ϕ = angle of repose of riprap

Riprap with a D_{50} calculated by the above equation will be on the threshold of movement at the flow value (q) used. The riprap layer will completely collapse at a flow varying from 120% (gravel) to 180% (crushed granite) of q [Stephenson, 1979].

8.1 Design Flow Per Unit Width (q)

$q = q_{max}$ See Section 7

8.2 Porosity of Riprap (n_p)

Porosities for different soil textures are shown in Table 3, where it can be seen that porosity decreases with increasing particle size, and for the coarsest soil listed (gravel), n_p = 0.397.

8.3 Empirical Factor (C)

C varies from 0.22 for gravel to 0.27 for crushed granite [Stephenson, 1979]. Using a low value of C (0.22) is conservative

8.4 Specific Gravity of Riprap, G_s

(BASED ON TEST RESULTS FROM QUARRIES)

8.5 Angle of Repose of Riprap (ϕ)

(FRICTION ANGLE 45° and 48° CALCULATED)

Written by: GPG Date: 00/12/15 (YY/MM/DD) Reviewed by: _____ Date: 00/12/15 (YY/MM/DD)

Client: _____ Project: _____ Project/Proposal No.: _____ Task No.: _____

COMPUTATION OF D_{50} REQUIRED USING STEPHENSON METHOD

INPUT PARAMETERS

FOR LITER'S STONE ($\phi = 48°$)

Flow Rate per unit Width	q	2.5	cfs/ft
Slope Angle	Theta	9.46	degrees
Porosity of Rock	np	0.397	
Empirical Constant	C	0.22	
Acceleration Due to Gravity	g	32.2	ft/sec2
Specific Gravity of Rock	Gs	2.63	
Angle of Repose of Rock	Phi	48	degrees

FOR MELVIN STONE ($\phi = 45°$)

Flow Rate per unit Width	q	2.5	cfs/ft
Slope Angle	Theta	9.46	degrees
Porosity of Rock	np	0.397	
Empirical Constant	C	0.22	
Acceleration Due to Gravity	g	32.2	ft/sec2
Specific Gravity of Rock	Gs	2.59	
Angle of Repose of Rock	Phi	45	degrees

CALCULATION (STEPHENSON METHOD - EQUATION)

$$D_{50} = \left[\frac{(2.5)(\tan 9.46°)^{7/6}(0.397)^{1/6}}{0.22(32.2)^{1/2}\left[(1-0.397)(2.63-1)\cos 9.46(\tan 48° - \tan 9.46°)\right]^{5/3}}\right]^{2}$$

$= 0.39$ FEET $= \underline{4.71}$ inches

$D_{50} = 0.46$ FEET $= \underline{5.56}$ inches

ATTACHMENT 6

Written by: GG Date: 00/12/15 Reviewed by: Date: 00/12/15

Client: Project: Project/Proposal No.: Task No.:

OVERSIZING D_{50} BASED ON OVERALL WEIGHTED SCORE

LITERS QUARRY

$\phi = 48°$, D_{50} (CALCULATED) = 4.71 inches

Overall weighted Score = 60

BASED ON UMTRA Procedure

$$\text{Oversizing factor} = 1 + \left[\frac{80-60}{100}\right] = 1.20$$

$$\text{Oversized } D_{50} = (4.71)(1.20)$$

$$= \underline{5.64 \text{ inches}}$$

MELVIN QUARRY

$\phi = 45°$, D_{50} (calculated) = 5.56 inches

Overall weighted Score = 56.9 ~ 57

BASED ON UMTRA PROCEDURE,

$$\text{Oversizing factor} = 1 + \left[\frac{80-57}{100}\right] = 1.23$$

$$\text{Oversized } D_{50} = (5.56)(1.23)$$

$$= \underline{6.83 \text{ inches}}$$

CONCLUSION

SINCE D_{50} FOR OHIO DOT CLASS D RIPRAP IS 6 INCHES, ONLY THE LITERS QUARRY WILL BE CONSIDERED FURTHER

ATTACHMENT 7

Written by: GG Date: 00/12/15 (YY MM DD) Reviewed by: _____ Date: 01/12/10 (YY MM DD)

Client: _____ Project: _____ Project/Proposal No.: _____ Task No.: _____

9. HARTUNG AND SCHEUERLEIN METHOD

The Hartung and Scheuerlein Method (H&S Method) [Hartung and Scheuerlein, 1970] is used to evaluate the resistance of the biointrusion barrier against gully advancement, should a gully erode through the overlying topsoil, vegetative support, and gravel choke layers. Hartung and Scheuerlein studied flow over riprap on steep slopes (10H:1V to 1.5H:1V), and developed their method for the purpose of designing rockfill dams to be overtopped. Knauss [1979] compared the H&S Method to Olivier's Method (the Stepehenson Method is based on Olivier's Method). Knauss found both to be in general agreement for slopes flatter than 5H:1V, but found the H&S Method to be reasonable and Olivier's Method over-conservative for steeper slopes. Based on this, Knauss recommended using the H&S Method on slopes of 5H:1V or steeper. Though the steepest slope on the OSDF final cover is 6H:1V (within the range Knauss found both methods to agree), the Hartung and Scheuerlein Method is used for comparison with the results of the Stephenson Method.

The steps for the Hartung and Scheuerlein Method are presented below:

9.1 Maximum Flow Depth in Gully, D

The maximum flow depth is an iterated variable. D is selected until the average flow velocity (v_{avg}) equals the critical velocity (v_{crit}). Both velocities are calculated in the steps that follow.

9.2 Aeration Factor (σ)

The aeration factor is calculated from the equation shown below[Hartung and Scheuerlein, 1970]:

$$\sigma = 1 - 1.3\sin\varphi + 0.08\frac{y_m}{\theta_m} \le 1$$

Where: φ = slope (6H:1V, Section 1.3)
y_m = mean flow depth
θ_m = mean roughness height

If σ = 1, there is no aeration in the flow and flow can be calculated with Manning's equation. Otherwise, Manning's equation is not valid [Hartung and Scheuerlein, 1970].

9.1.1 Mean flow depth (y_m)

See Figure 16

AI DGP 02/14/01

9.1.2 Mean roughness height (θ_m)

$\theta_m \approx D_{50}/3$ [Hartung and Scheuerlein, 1970] Where: D_{50} = mean diameter of riprap (= ~~0.305~~ 0.152 m)

9.2 Flow Coefficient, c

$c = \sigma(1.7 + 8.1\Phi\sin\varphi)$ Where: Φ = packing factor

9.2.1 Packing factor (Φ)

The packing factor varies from 0.625 for "dumped" or "natural" packing to 1.125 for "manual" packing "with flat stones placed on edge" [Knauss, 1979]

9.3 Resistance Factor (λ)

The equation for the resistance factor is [Hartung and Scheuerlein, 1970]:

$$\frac{1}{\sqrt{\lambda}} = -3.2\log\left(c\frac{\theta_m}{4y_m}\right)$$

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9.4 Average Velocity (v_{avg})

The equation for average flow velocity is [Hartung and Scheuerlein, 1970]:

$$v_{avg} = \sqrt{\frac{8g}{\lambda}}\sqrt{y_m \sin\varphi}$$

Where: g = acceleration of gravity (9.81 m/s^2)

9.5 Critical Velocity (v_{crit})

The equation for critical velocity (the velocity at which riprap stones will begin to move) is [Hartung and Scheuerlein, 1970]:

$$v_{crit} = 1.2\sqrt{\frac{2g(G_s - 1)\gamma_w}{\sigma\gamma_w}}\sqrt{d_s \cos\varphi}$$

Where: G_s = specific gravity of riprap (assume G_S = 2.65 per USDOE [1989])
γ_w = unit weight of water = 1 g/cm^3

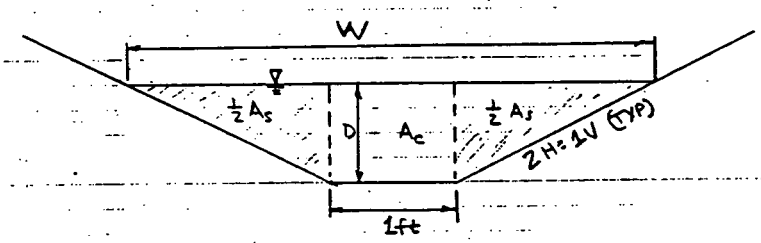
If $v_{crit} \geq v_{avg}$, the riprap should not erode (gullies should not penetrate the biointrusion barrier)

9.6 Allowable Flow Per Unit Width (q_{all})

The equation for allowable flow per unit width is [Hartung and Scheuerlein, 1970]:

$$q_{all} = \sigma y_m v_{crit}$$

If $q_{all} \geq q_{max}$, the riprap should not erode (gullies should not penetrate the biointrusion barrier). q_{max} is calculated in Section 7.



$W = 1ft + 2D(2) \rightarrow W - 1 = 4D$

$A_c = D \qquad A_s = \frac{1}{2}[(W-1)D] = 2D^2$

$$y_m = \frac{D A_c + \frac{D}{2} A_s}{A_c + A_s} = \frac{D^2 + D^3}{D + 2D^2} = \frac{D + D^2}{1 + 2D}$$

y_m = MEAN FLOW DEPTH

Figure 16 - Procedure For Calculating Mean Flow Depth, y_m, in a Trapezoidal Channel With a 1-foot Wide Base

HARTUNG AND SCHEUERLEIN METHOD
(EVALUATION OF STONE FROM LITERS QUARRY)

ITERATIVELY SOLVE FOD D

Riprap D50 =	6	inches =	0.1524	meters
Assumed D =	0.615	feet =	0.187452	meters

AERATION FACTOR

Mean Flow Depth	Y_m =	0.45	feet =	0.135756	meters
Mean Roughness Height	θ_m =	0.05	meters		
Slope Angle	φ =	9.46	degrees =	0.17	radians
Aeration Factor	σ =	1.00			
Maximum Value of Aeration Factor	σ =	1.00			

FLOW COEFFICIENT

Packing Factor	Φ =	0.63			
Slope Angle	φ =	9.46	degrees =	0.17	radians
Aeration Factor	σ =	1.00			
Flow Coefficient	C =	[illegible]			

RESISTANCE FACTOR

Flow Coefficient	C =	2.53	
Mean Roughness Height	θ_m =	0.05	meters
Mean Flow Depth	Y_m =	0.14	meters
Resistance Factor	$1/(\lambda)^{0.5}$ =	2.00	
	λ =	0.25	

AVERAGE VELOCITY

	λ =	0.25			
Mean Flow Depth	Y_m =	0.14	meters		
Slope Angle	φ =	9.46	degrees =	0.17	radians
Acc. Due to gravity	g =	9.81	m/sec2		
Average Velocity	V_{avg} =	2.64	m/s		

$V_{avg} = V_{crit}$

CRITICAL VELOCITY

Specific Gravity of Stone	Gs =	2.65			
Unit Weight of Water	γ_w =	1.00	g/cm^3		
D50 of Riprap	ds =	0.15	m		
Slope Angle	φ =	9.46	degrees =	0.17	radians
Aeration Factor	σ =	1.00			
Acc. Due to gravity	g =	9.81	m/sec2		
Crictical Velocity	V_{crit} =	[illegible]	m/s		

ALLOWABLE FLOW PER UNIT WIDTH

Crictical Velocity	V_{crit} =	2.647	m/s		
Mean Flow Depth	Y_m =	0.14	meters		
Aeration Factor	σ =	1.00			
Allowable flow per unit width	q_{all} =	0.359	m^3/s per m =	3.868	ft^3/s per ft

MAXIMUM FLOW PER UNIT WIDTH (2000-YEAR) ✓

q_{max} = 2.50 CFS/FT < q_{all} = 3.87 CFS/FT ✓

Hence, D_{50} = 6" is acceptable based on this method.

ATTACHMENT 8

3496

Written by: LMG Date: 00 / 11 / 29 (YY MM DD) Reviewed by: Date: / / (YY MM DD) 25/36

Client: FLUOR FERNALD Project: Project/Proposal No.: Task No.:

□ BIOINTRUSION BARRIER

CHOKE STONE

BIOINTRUSION BARRIER

□ ASSUME.

BIOINTRUSION BARRIER → ROCKFILL TYPE D

CHOKE STONE → OHIO DOT #57 STONE

□ FILTER REQUIREMENT

$$\frac{d_{15\,\text{BIOINTRUSION}}}{d_{85\,\text{CHOKE STONE}}} \leq 5$$

□ GRAIN SIZE DISTRIBUTION CURVE

FIGURE 1. BIOINTRUSION BARRIER

d_{15} = 75 mm

d_{85} = 300 mm

FIGURE 2. CHOKE STONE

d_{15} = 6 to 10 mm

d_{85} = 16 to 20 mm

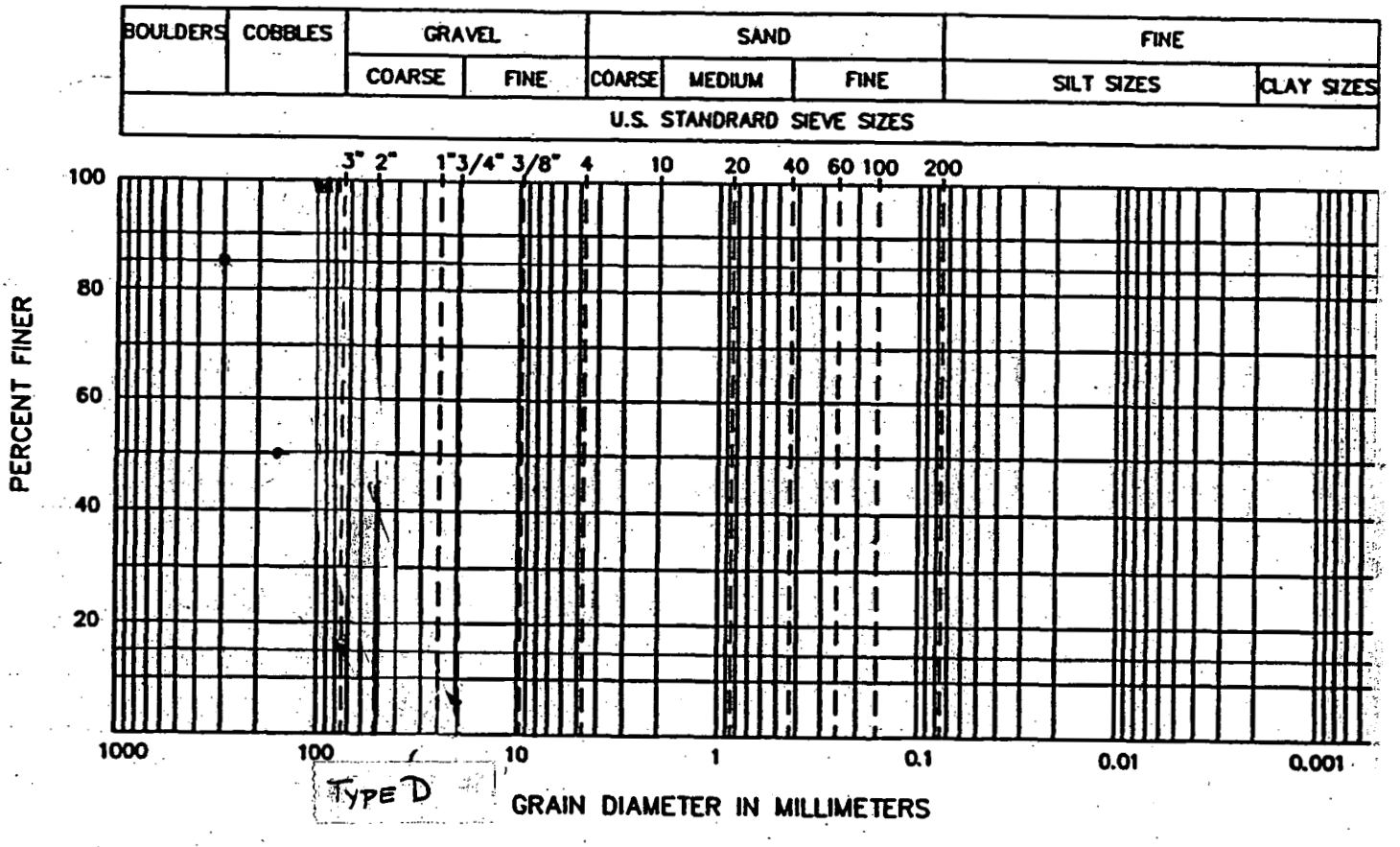
MAD 96/2/19

Written by: PJP Date: 96 / 02 / 17 (YY MM DD) Reviewed by: PJS Date: 96 / 2 / 26/36 17 (YY MM DD)

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 8.8

FIGURE 1.

ROCKFILL TYPE D has the following approximate grain-size curve:



This gives a d_{15} = 75 mm and a d_{85} = 300 mm

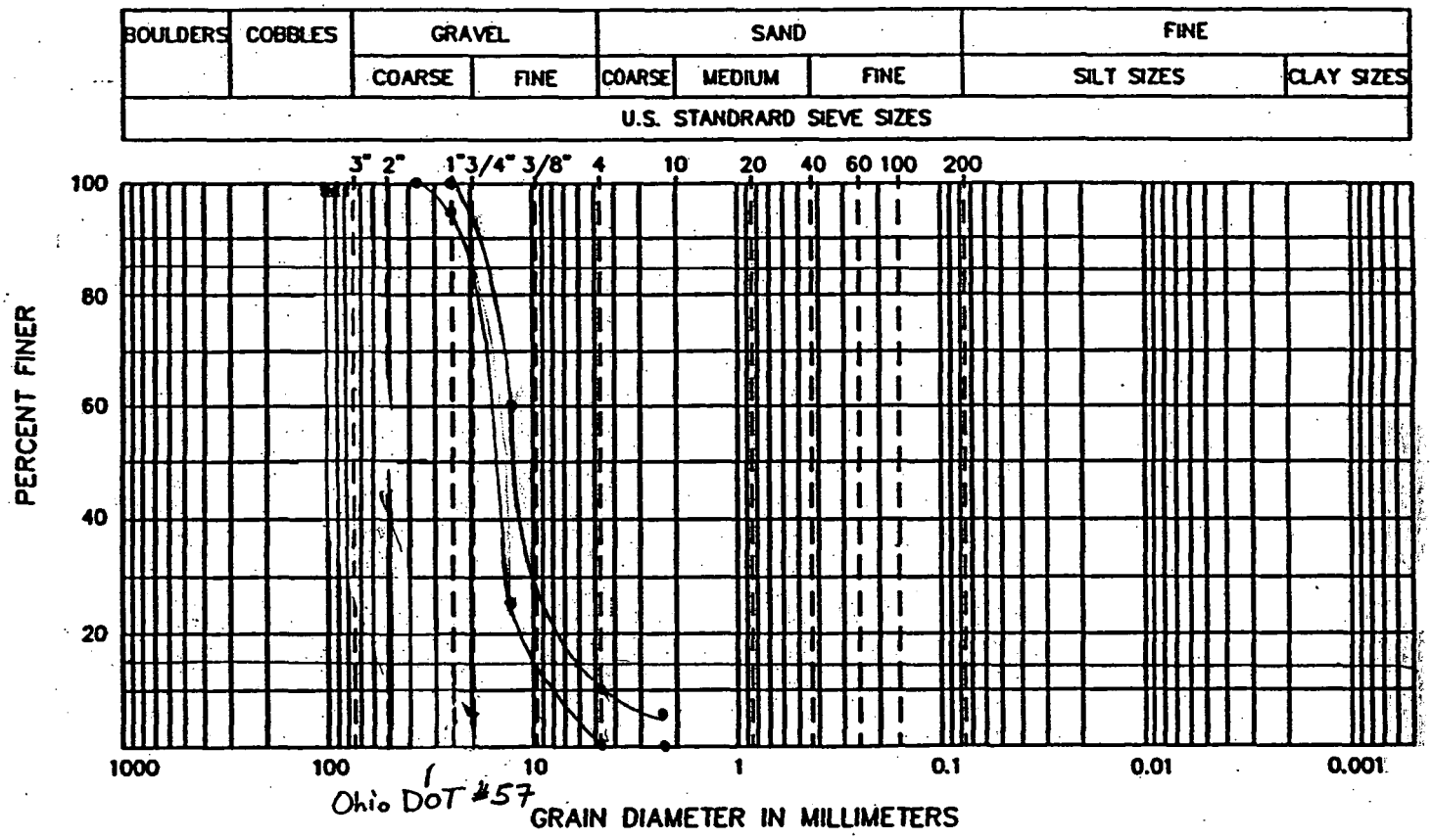
MAO 96/2/19

Written by: PJP Date: 96 / 02 / 17 Reviewed by: PJS Date: 96 / 27/36 / 17

Client: FERMCO Project: FERNALD OSDF Project/Proposal No.: GE3900 Task No.: 8.8

FIGURE 2.

Ohio DOT #57 stone has the following approximate grain-size curve:



This gives a d_{15} = 6 TO 10 MM and a d_{85} = 16 TO 20 MM

CHOKE STONE REQUIREMENT

$$\frac{d_{15\,BIOINTRUSION}}{d_{85\,CHOKE\,STONE}} \leq 5$$

USE. $d_{15\,BIOINTRUSION}$ = 75 mm

$d_{85\,CHOKE\,STONE}$ = 16 MM

$$\frac{d_{15\,BIOINTRUSION}}{d_{85\,CHOKE\,STONE}} = \frac{75\text{ mm}}{16\text{ mm}} = 4.7 < 5 \quad \text{OK}$$

Written by: LMG Date: 00 / 11 / 29 (YY MM DD) Reviewed by: Date: / / (YY MM DD)

Client: FLUOR FERNALD Project: Project/Proposal No.: Task No.:

□ GRANULAR FILTER

CASE I:

VEGETATIVE SOIL LAYER	→ FINE-GRAINED GRAY TILL
GRANULAR FILTER	→ ODOT ITEM 703.06
COVER DRAINAGE LAYER	→ AASHTO M43 No. 78

CASE II.

GRANULAR FILTER	→ ODOT ITEM 703.06
CHOKE STONE	→ AASHTO M43 No. 57
BIOINTRUSION BARRIER	→ ROCKFILL TYPE D

CASE I:

VEGETATIVE SOIL LAYER TO GRANULAR FILTER

$$\frac{d_{15}\text{ (GRANULAR FILTER)}}{d_{85}\text{ (VEGETATIVE SOIL LAYER)}} \leq 15$$

GRANULAR FILTER TO COVER DRAINAGE LAYER:

$$\frac{d_{15}\text{ (COVER DRAINAGE LAYER)}}{d_{85}\text{ (GRANULAR FILTER)}} \leq 5 \checkmark$$

CASE II:

GRANULAR FILTER TO CHOKE STONE:

$$\frac{d_{15}\text{ (CHOKE STONE)}}{d_{85}\text{ (GRANULAR FILTER)}} \leq 5 \checkmark$$

Δ1 DGP 02/14/01
A ratio of 15 is selected based on guidance presented in Cedergren (1989) for protecting a plastic clay soil from piping into a filter. The gray and brown till CL material expected for use as a vegetative soil material is a plastic clay. Cedergren states "If the protected soil is a plastic clay, the piping ratio often can be much higher than 5 or 10." Based on a review of geotechnical data for the brown and gray tills, typical hydraulic conductivities have been achieved on the order of 10^{-7} and 10^{-8} cm/sec which is consistent with a plastic clay with a low potential for piping. Thus, considering the guidance quoted above from Cedergren a ratio of 15 was selected as a filter criteria between the granular filter and choke stone layers.

□ GRAIN SIZE DISTRIBUTION CURVE

FIGURE 3. VEGETATIVE SOIL LAYER

d_{15} = <0.001 to 0.0028 mm

d_{85} = 0.032 to 3.8 mm ✓

Written by: LMG Date: / / YY MM DD Reviewed by: Date: / / YY MM DD

Client: FLUOR FERNALD Project: Project/Proposal No.: Task No.:

FIGURE 4. GRANULAR FILTER

d_{15} = 0.12 to 0.48 mm

d_{85} = 1.9 to 4 mm

FIGURE 5. COVER DRAINAGE LAYER

d_{15} = 2.6 to 5.8 mm

d_{85} = 10 to 12 mm

CASE I:

VSL TO GF → $\frac{d_{15(GF)}}{d_{85(VSL)}} \leq 15$

$\frac{0.48}{0.032} = 15$ OK

GF TO CDL → $\frac{d_{15(CDL)}}{d_{85(GF)}} \leq 5$

$\frac{5.8\ mm}{1.9\ mm} = 3.1 < 5$ OK

CASE II:

GF TO CS → $\frac{d_{15(CS)}}{d_{85(GF)}} \leq 5$

$\frac{10\ mm}{1.9\ mm} = 5$ OK

A1 DGP 02/14/01
The calculated ratio d_{15}/d_{85} rounded to one significant digit to the right of the decimal place would be 5.3. The calculated ratio is presented as a whole number consistent with the criteria being defined as a whole number.

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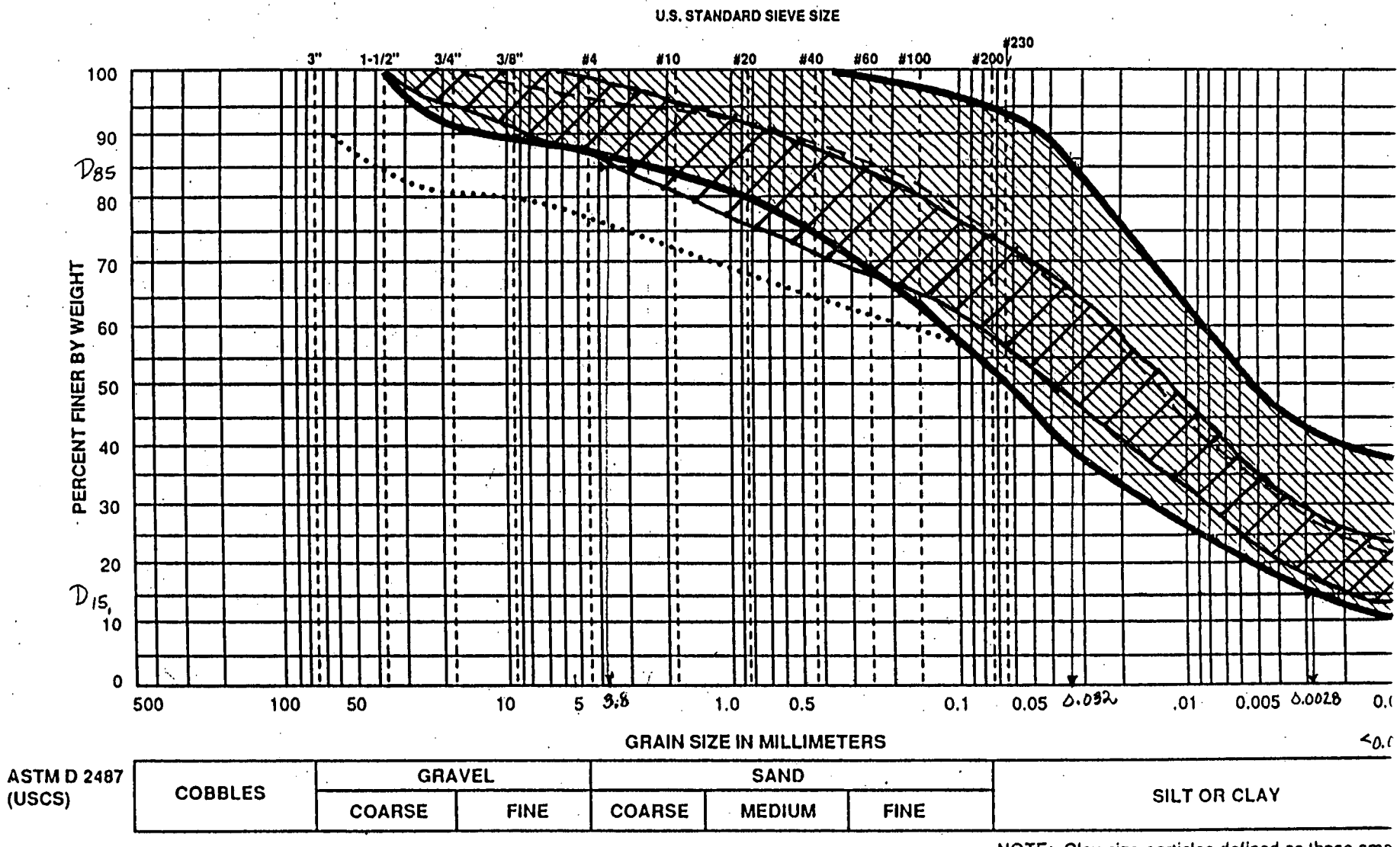

Range of 27 fine-grained brown till CL samples (excludes outliers)

Mode from visual inspection

Outlier (1 total)

Range of 36 fine-grained gray till CL samples (excludes outliers)

NOTE: Clay size particles defined as those sma than 0.005 mm (Ref. ASTM D 422)

Project No.: PO-132

3496

30/36

FINE-GRAINED BROWN AND GRAY TILL [from Pagano 1995]

ERAFS1\VOL1:RSAPPS\RSDATA\
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06/29 10:33am, Rev. No.: 0

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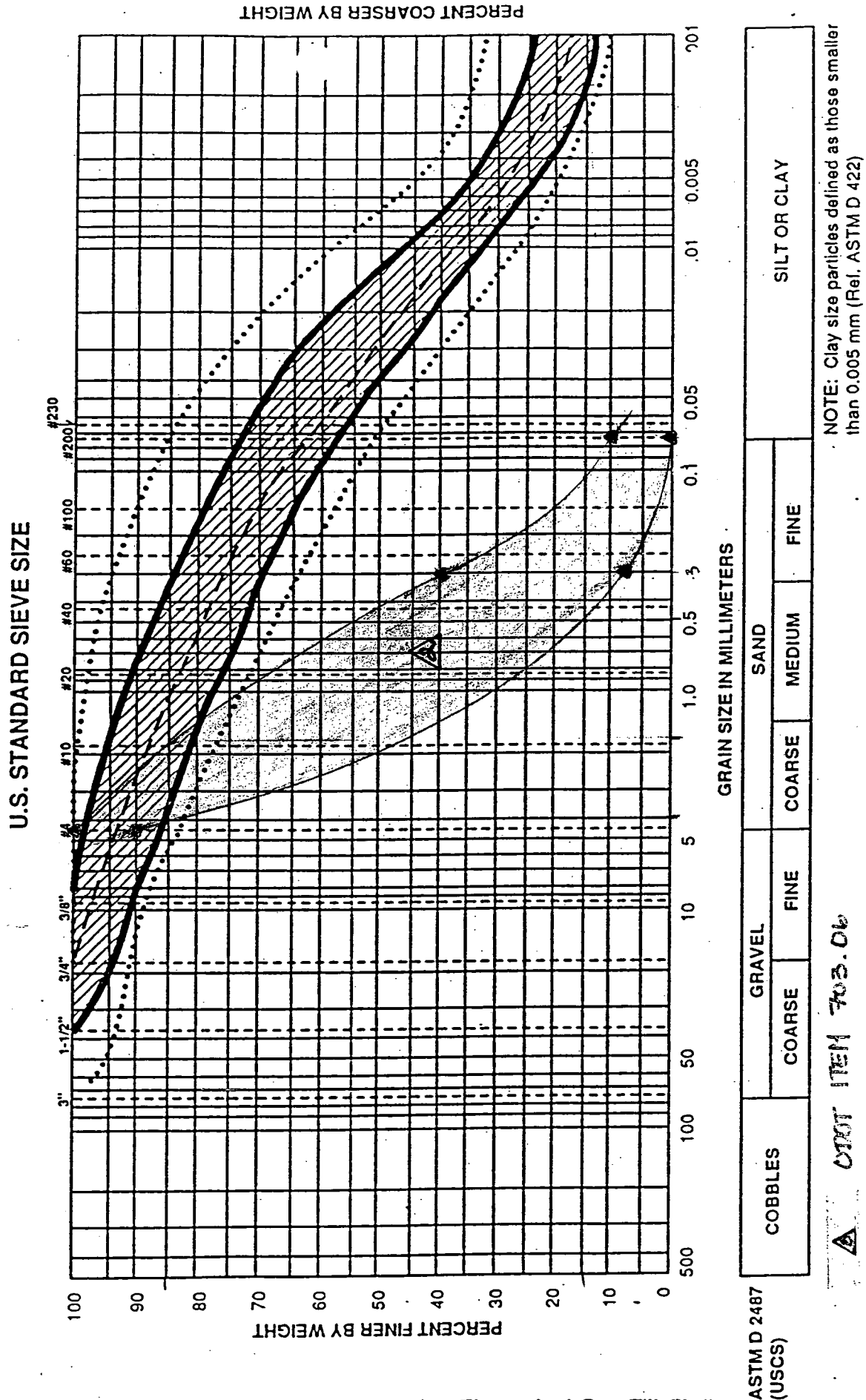

NOTE: Clay size particles defined as those smaller than 0.005 mm (Rel. ASTM D 422)

Project No.: PO-132

CTOT ITEM 703.06

FIGURE 4. GRAIN-SIZE DISTRIBUTION OF GRANULAR FILTER

Figure 4-2 - Grain-size Distribution, Fine-grained Gray Till CL Samples

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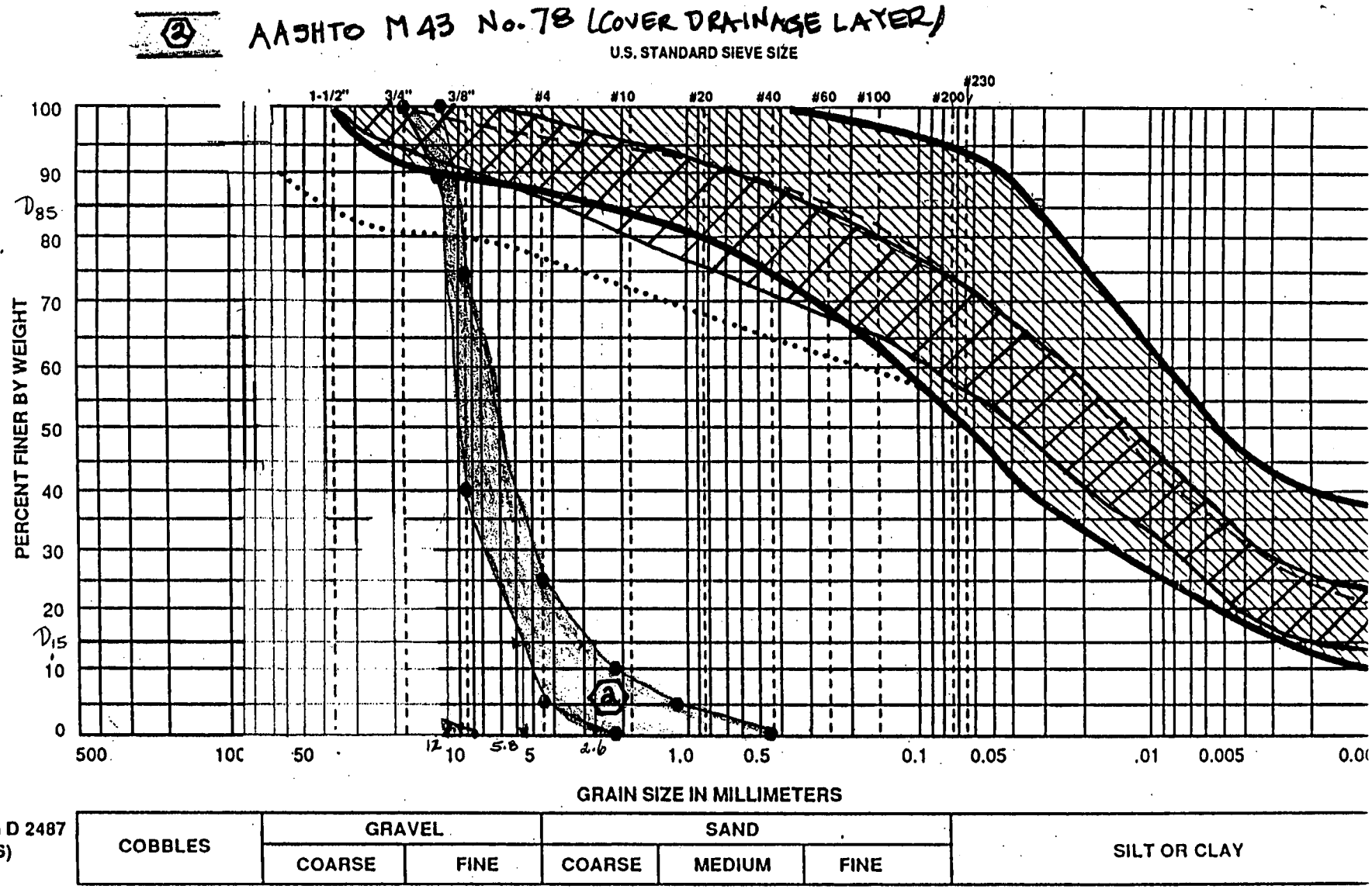

ASTM D 2487 (USCS)	COBBLES	GRAVEL		SAND			SILT OR CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE	

Range of 27 fine-grained brown till CL samples (excludes outliers)

Mode from visual inspection

Outlier (1 total)

Range of 36 fine-grained gray till CL samples (excludes outliers)

NOTE: Clay size particles defined as those small than 0.005 mm (Ref. ASTM D 422)

Project No.: PO-132

3496

32/36

FIGURE 5 GRAIN-SIZE DISTRIBUTION OF THE VEGETATIVE SOIL LAYER, COVER DRAINAGE LAYER

Written by: Ganesh Gopalakrishnan (GG) Date: 12/16/00 Reviewed by: John F. Beech (JFB) Date: 15 Dec 00

Client: Fluor Fernald Project: Re-evaluation - Biointrusion Barrier Project/Proposal No.: GQ1030 Task No.: 14

ATTACHMENT 9

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