NRC Request for Information

Atlas Corporation Reclamation Plan Uranium Mill and Tailings Disposal Area

94-0223

Canonie Environmental

PARTIAL RESPONSE TO NUCLEAR REGULATORY COMMISSION
REQUEST FOR INFORMATION
ENCLOSURE 2 - OTHER CONSIDERATIONS
RECLAMATION PLAN
URANIUM MILL TAILINGS SITE
MOAB, UTAH

INTRODUCTION

Canonie Environmental Services Corp. (Canonie) has prepared a response to the Nuclear Regulatory Commission's (NRC's) request for information in its letter dated November 29, 1993. This response is a partial response to the information requested in Enclosure 2 of this letter. The Enclosure 2 request for information relates to erosion protection, radon attenuation, construction specifications and settlement considerations at Atlas Corporations's (Atlas') Moab site. This partial response addresses erosion protection at Moab Wash and the Lower Impoundment Drainage Channel, construction specifications, and settlement. The responses to Enclosure 1 (November 29, 1993 request for information) and the remainder of the responses to Enclosure 2 will be submitted on March 29, 1994. A response to the January 3, 1994 request for information will also be submitted on March 29, 1994. The Enclosure provided with the January 3, 1994 letter presents additional questions and comments concerning surface water hydrology and erosion protection. In the following pages, each request for information is restated verbatim and a response for each request is provided.

A. EROSION PROTECTION

Comment

2. Along with the question on the effect of floods in Moab Wash on the tailings pile, previously transmitted by our letter of April 20, 1993, it appears that the erosion protection for the Lower Impoundment Drainage Channel could also be affected by Moab Wash. If Moab Wash were to

> migrate and/or erode a channel near the proposed outlet of this channel, the erosion protection design proposed for the channel may not be adequate to accommodate the flow velocities and shear forces in Moab Wash. Therefore, you should substantiate that the erosion protection is adequate to resist the velocities in Moab Wash, or revise the design accordingly, and submit for our review and approval.

Response

The erosion protection for the Lower Impoundment Drainage Channel is not expected to be affected by flows from Moab Wash if Moab Wash were to migrate and/or erode a channel near the outlet of the proposed Lower Impoundment Drainage Channel. Canonie (Response to NRC Comments, April 1993) presented a design for a buried rock cutoff wall at the outlet of the Lower Impoundment Drainage Channel. The rock cutoff wall design calculations previously submitted in April 1993 have been included in Appendix A of this document. Enclosed in Appendix B of this document are calculations for a buried rock wall along the base of the northern regraded tailings embankment (10H:3V slope) designed to protect the embankment from encroachment by Moab Wash. Sheet 4 of 10 and sheet 7 of 10 of the drawings have been revised to reflect this buried rock wall. These figures are included in this document. The rock cutoff wall at the outlet of the Lower Impoundment Drainage Channel was designed to withstand a greater velocity, greater shear, and larger depth of scour than what is expected under a Probable Maximum Flood (PMF) event in Moab Wash (when Moab Wash inner channel has migrated near the proposed outlet of the Lower Impoundment Drainage Channel). Therefore, the Lower Impoundment Drainage Channel is not expected to be affected by Moab Wash flows. A summary of the design calculations presented in Appendices A and B of this document is provided below.

The rock cutoff wall at the outlet of the Lower Impoundment Drainage Channel was designed to accommodate a depth of scour of 8 feet. A 26-inch riprap layer thickness of 17.4-inch D50 (median stone size) was designed for the Lower Impoundment Channel (including the rock cutoff wall) to withstand an average velocity of 13 feet per second (fps) and an average local boundary shear of 4.6 pounds per square foot (psf).

With respect to Moab Wash in the vicinity of the Lower Impoundment Drainage Channel and to the east [sections L-L', M-M' and N-N' on Drawing No. 88-067-E66 (Sheet 4 of 10)], design calculations submitted in Appendix B of this document indicate that 9-inch D50 rock wall is required to protect the embankment from encroachment by Moab Wash. The 9-inch rock wall at Sections L-L', M-M' and N-N' were designed to withstand a velocity of 11.7 fps, local boundary shear of 2.4 psf and depth of scour of 6.7 feet. The riprap for Moab Wash and the rock cutoff wall at the outlet of the Lower Impoundment Drainage Channel was sized based on the PMF event in Moab Wash using the U.S. Army Corps of Engineers (allowable local shear stress) method. Toe protection for the channel bank protection and scour depth were considered in the calculations. Based on this analysis, erosion protection is adequate to resist the velocities in Moab Wash.

C. CONSTRUCTION SPECIFICATIONS

Comment

1. The quality control program for placement depths of the clay and sandy soil layers which comprise the radon barrier sets tolerances at plus or minus 0.1 foot as measured on a 200-foot grid system. (Reference Specification Sections 5.3.2, June 4, 1992, and Section 5.3.4, April 14, 1993.) The depths associated with the radon barrier may not be less than the design depth. Accordingly, justify the proposed specification or modify the specification accordingly.

Response

The sentences indicating the clay and sandy soil layer thickness tolerance of ± 0.1 foot will be eliminated from Section 5.3.2 and 5.3.4 of the Specifications.

Comment

2. The specifications indicate that the bulk specific gravity should be determined by ASTM C 97. This ASTM designation is incorrect; the bulk specific gravity

of the rock should be determined by ASTM C 127. Modify the specification to the correct reference.

Response

The Specifications will be modified to indicate that ASTM: C 127-88, Test Method for Specific Gravity and Absorption of Coarse Aggregate will be used to determine bulk specific gravity.

Comment

3. Durability testing of the rock in the rock/soil matrix is not specified. The testing of the rock portion of the soil/rock matrix should be performed at the same frequency as that specified for riprap in Section 9.3.4.1 of the specifications dated April 14, 1993. Modify the specifications accordingly or justify the lack of durability testing for the rock portion of the rock/soil matrix.

Response

Section 9.3.5, Soil/Rock Matrix Placement, Compaction, and Testing, will be modified to include the rock durability testing requirements in accordance with NRC's August 1990 STP requirements. The durability testing frequency will include a minimum of initial testing before use as indicated in Section 6.3.1 and testing for each additional 10,000 cubic yards of rock from a particular source. Additional tests will be conducted more frequently than every 10,000 cubic yards when the rock characteristics (i.e., color, texture) in the rock borrow source vary significantly from the rock that was previously tested.

D. SETTLEMENT

Comment

1. Based on its continuing review of the geotechnical engineering design, the staff has determined that a quantitative estimate of potential embankment

settlement should be made. Settlement estimates could be based on a field program including soil test borings and/or piezocones, with soil laboratory testing as appropriate. Alternatively, the Licensee may base its estimates on observational methods. If the Licensee used observational methods to verify that settlements will be controlled, then procedures for monitoring settlement and criteria for assessing attainment of adequate settlement should be provided.

Based on the results of the test drilling/laboratory programs, or the alternative observational approach, the Licensee should confirm that excess settlement resulting in cover cracking or other modes of instability will not occur with the given design. It is understood that the tailings may be highly stratified, and that modeling will be subject to interpretation of the geotechnical engineer. For this reason, a justification for any simplifying assumptions should be included in the submittal.

Response

Section 9.3.1 of the Specifications discusses the execution of settlement monitoring. Settlement monitoring will be initiated immediately upon completion of regrading and material placement (i.e., windblown tailings, affected soils, and ore). The monitoring, involving elevation readings of the settlement monitoring platforms, will continue until primary consolidation has occurred. Magnitude of settlement versus logarithm of time plots will be generated during the monitoring period. When 90 percent of primary consolidation has occurred the final soil cover placement will begin. To supplement the settlement monitoring data, in-situ testing will be performed to provide additional data from which to perform settlement estimates prior to final cover placement. Piezocone measurements will be performed in the vicinity of the settlement monitoring platforms to obtain results on shear strength and hydraulic and consolidation parameters. Atlas will determine when primary consolidation is complete, as approved by the NRC. The specifications will be modified to discuss in-situ testing and settlement estimates of the tailings embankment prior to final cover placement. During and following final soil cover placement, settlement will be monitored on a weekly basis.

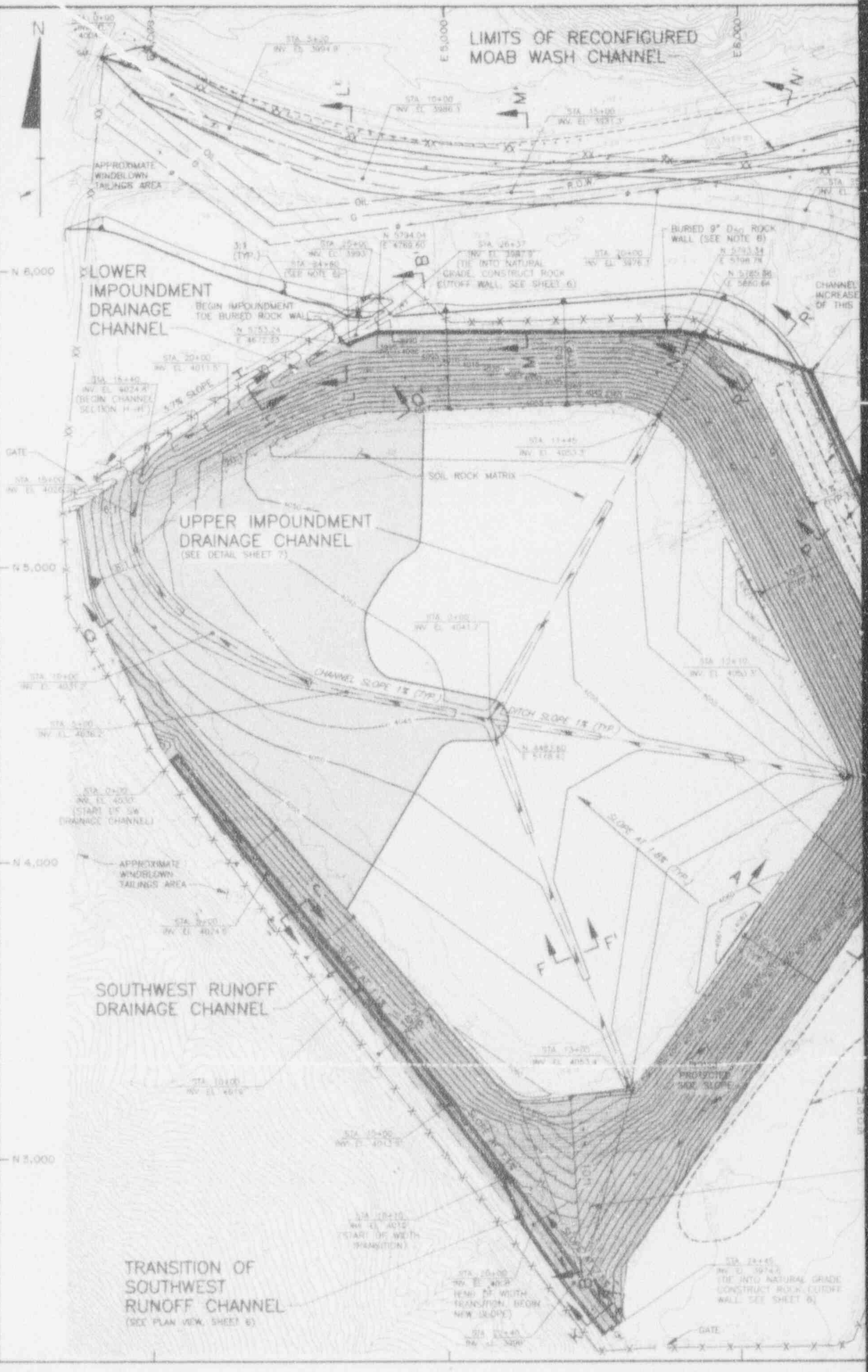
FIGURES

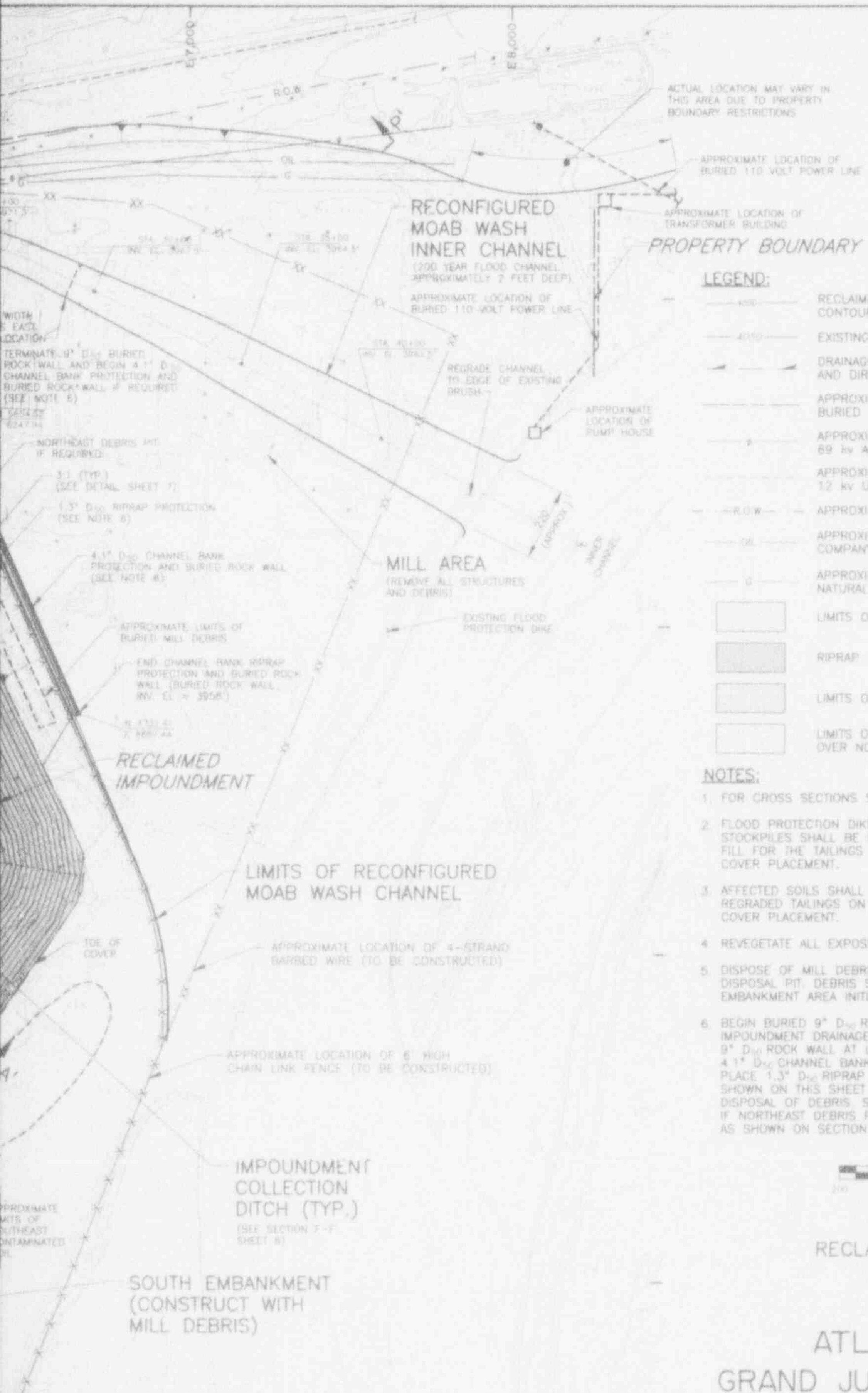
DRAWING NUMBER 88-067-E66

CHECKED BY

APPROVED BY

DRAWN BY



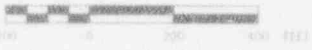


LEGEND:

4000	RECLAIMED IMPOUNDMENT DESIGN CONTOURS, FEET
4050	EXISTING TOPOGRAPHIC CONTOURS, FEET
— — —	DRAINAGE DITCH LOCATION AND DIRECTION OF FLOW
— · —	APPROXIMATE CONTEL AERIAL AND BURIED TELEPHONE CABLES
P	APPROXIMATE UTAH POWER AND LIGHT 69 kv AERIAL POWER LINE
—	APPROXIMATE UTAH POWER AND LIGHT 12 kv UNDERGROUND CABLE
R.O.W.	APPROXIMATE HIGHWAY RIGHT OF WAY
OIL	APPROXIMATE 10" ø MIDAMERICAN PIPE COMPANY LIQUID LINE
G	APPROXIMATE 26" ø NORTHWESTERN NATURAL GAS LINE
☐	LIMITS OF 1.3" D_{50} SOIL/ROCK MATRIX
▨	RIPRAP
☐	LIMITS OF 3.0" D_{50} SOIL/ROCK MATRIX
☐	LIMITS OF 1.3" D_{50} RIPRAP PROTECTION OVER NORTHEAST DEBRIS PIT (SEE NOTE 6)

NOTES:

1. FOR CROSS SECTIONS SEE SHEETS 5,6 AND 7.
2. FLOOD PROTECTION DIKE, WINDBLOWN TAILINGS, AND ORE STOCKPILES SHALL BE REMOVED AND USED AS REGRADING FILL FOR THE TAILINGS IMPOUNDMENT, PRIOR TO SOIL COVER PLACEMENT.
3. AFFECTED SOILS SHALL BE EXCAVATED AND PLACED OVER REGRADED TAILINGS ON IMPOUNDMENT TOP PRIOR TO SOIL COVER PLACEMENT.
4. REVEGETATE ALL EXPOSED DISTURBED SOIL.
5. DISPOSE OF MILL DEBRIS IN SOUTH EMBANKMENT AND NORTHEAST DISPOSAL PIT. DEBRIS SHALL BE DISPOSED OF IN SOUTH EMBANKMENT AREA INITIALLY.
6. BEGIN BURIED 9" D_{50} ROCK WALL AT STA. 24+60 OF THE LOWER IMPOUNDMENT DRAINAGE CHANNEL (EAST BANK). TERMINATE BURIED 9" D_{50} ROCK WALL AT LOCATION SHOWN ON THIS SHEET. CONSTRUCT 4.1" D_{50} CHANNEL BANK PROTECTION AND BURIED ROCK WALL AND PLACE 1.3" D_{50} RIPRAP OVER NORTHEAST DEBRIS PIT AT THE LOCATIONS SHOWN ON THIS SHEET <u>ONLY</u> IF NORTHEAST DEBRIS PIT IS USED FOR DISPOSAL OF DEBRIS. SEE SHEET 7 FOR DETAILS AND CROSS SECTIONS. IF NORTHEAST DEBRIS PIT IS NOT CONSTRUCTED, EXTEND ROCK ARMOR AS SHOWN ON SECTION A-A' TO MEET 9" D_{50} BURIED WALL.



PLAN VIEW OF
RECLAIMED IMPOUNDMENT

PREPARED FOR

ATLAS MINERALS
GRAND JUNCTION, COLORADO

Canonie Environmental

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
2	1-17-94	ISSUED TO COMPLY WITH NRC LICENSE CONDITION NO. 4; NOT FOR CONSTRUCTION	P.M.W.	J.A.T.	[illegible]
1	4-15-93	ISSUED FOR RESPONSE TO NRC COMMENTS	B.K.R.	J.M.O.	D.W.K.

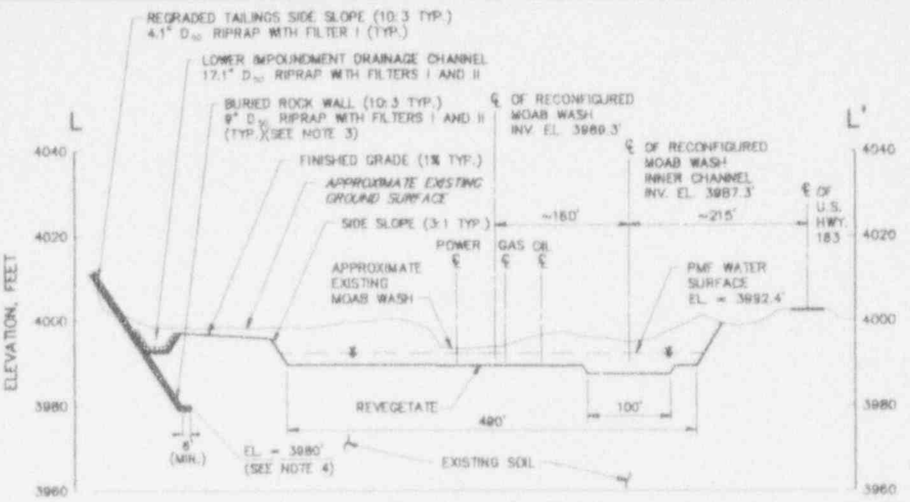
88-067-L4

DATE: 4-7-93 SCALE: AS SHOWN	SHEET 4 of 10	DRAWING NUMBER 88-067-E66

88-067-E14

9402240074-01

DRAWN BY	R.H. 7-23-88	CHECKED BY APPROVED BY	P.E.C. O.P.W.	8-4-88 8-4-88	DRAWING NUMBER 88-067-E16



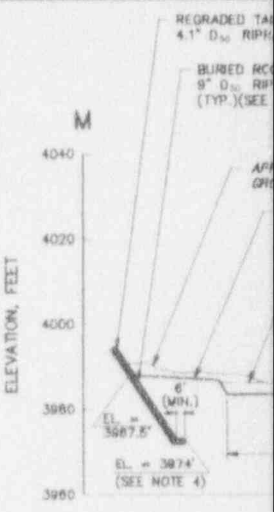
SECTION L–L'

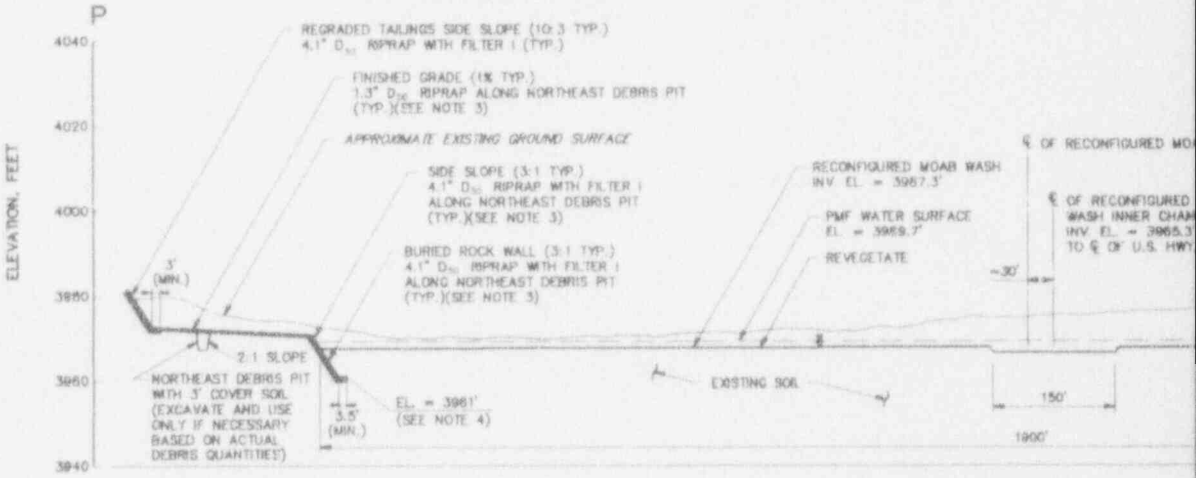
RECONFIGURED MOAB WASH AND IMPOUNDMENT TOE PROTECTION

(LOOKING WEST)

NOTE:

1. BEGIN BURIED ROCK WALL BELOW ELEVATION OF LOWER IMPOUNDMENT DRAINAGE CHANNEL RIPRAP AND FILTER LAYERS.

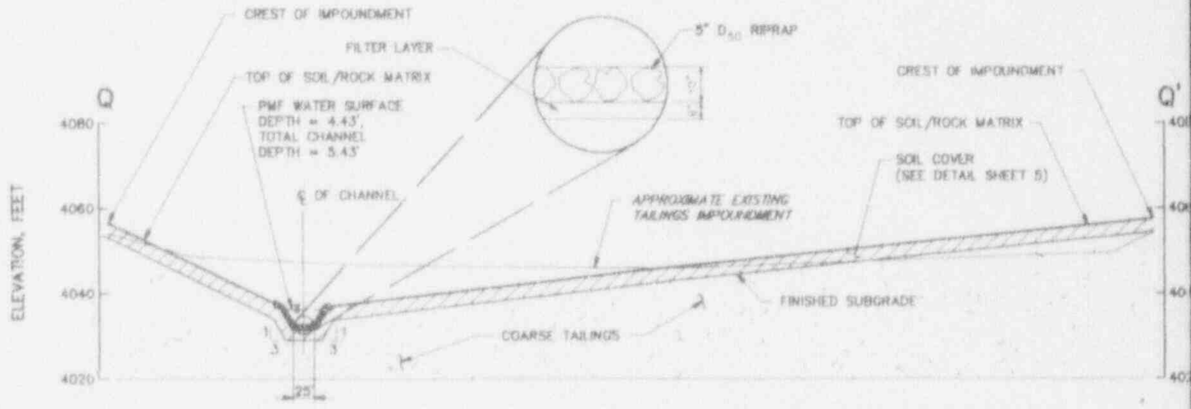




SECTION P–P'

RECONFIGURED MOAB WASH AND IMPOUNDMENT TOE PROTECTION

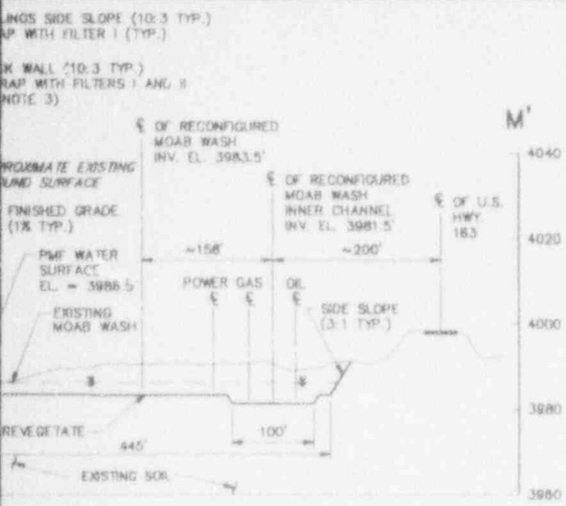
(LOOKING NORTHWEST)



SECTION Q–Q'

UPPER IMPOUNDMENT DRAINAGE CHANNEL

(LOOKING NORTHWEST)



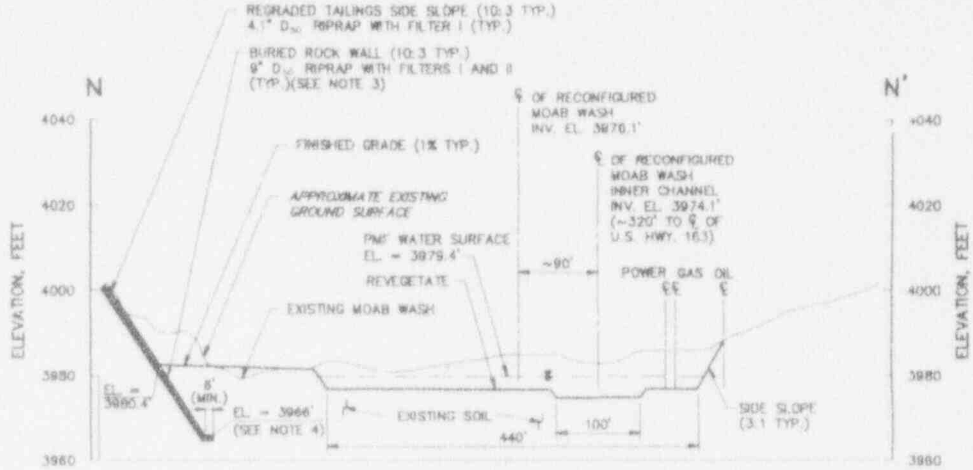
SECTION M–M'

RECONFIGURED MOAB WASH AND IMPOUNDMENT TOE PROTECTION

(LOOKING WEST)

NOTE:

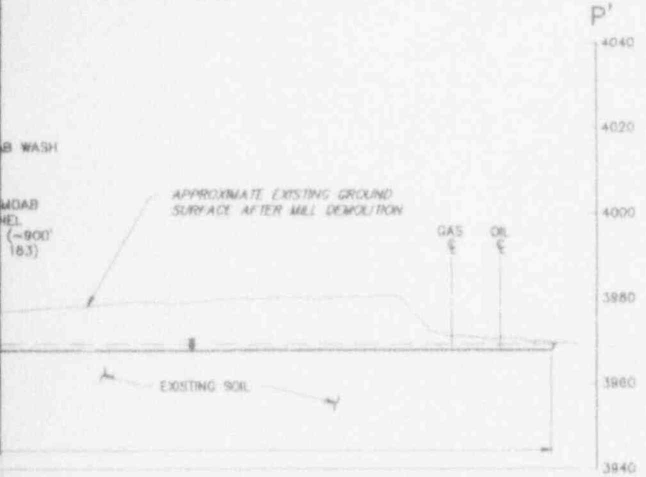
1. UTILITIES TO BE RELOCATED PRIOR TO CHANNEL EXCAVATION.



SECTION N–N'

RECONFIGURED MOAB WASH AND IMPOUNDMENT TOE PROTECTION

(LOOKING NORTHWEST)



LEGEND:

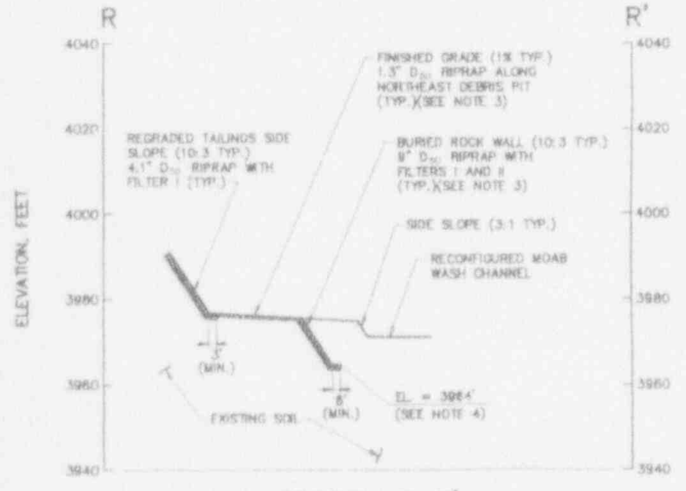
POWER ℄ — APPROXIMATE CENTERLINE OF UTAH POWER AND LIGHT 69 kv AERIAL POWER LINE

GAS ℄ — APPROXIMATE CENTERLINE OF 26" DIA. NORTHWESTERN GAS LINE

OIL ℄ — APPROXIMATE CENTERLINE OF 10" DIA. MIDAMERICAN PIPE COMPANY LIQUID LINE

NOTES:

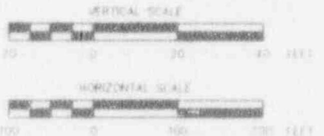
1. FOR PLAN LOCATION OF SECTIONS, SEE SHEET 4.
2. SEE SPECIFICATIONS FOR RIPRAP AND FILTER MATERIAL REQUIREMENTS. RIPRAP AND FILTERS ARE NOT SHOWN TO SCALE. SEE SPECIFICATIONS FOR THICKNESSES BY LOCATION.
3. BURIED 9" D_{50} ROCK WALL WILL BE CONSTRUCTED BEGINNING AT APPROXIMATELY STA. 24+60 ON THE LOWER IMPOUNDMENT DRAINAGE CHANNEL (EAST BANK) AND TERMINATING AS SHOWN ON SHEET 4. 4.1" D_{50} CHANNEL BANK PROTECTION AND BURIED ROCK WALL AND 1.3" D_{50} RIPRAP OVER NORTHEAST DEBRIS PIT SHALL BE CONSTRUCTED ONLY IF NORTHEAST DEBRIS PIT IS USED FOR DISPOSAL OF DEBRIS.
4. BURIED ROCK WALL CONFIGURATION AND ELEVATIONS SHALL BE AS SHOWN ON SECTIONS L–L', M–M', N–N', P–P', AND R–R', AND SHALL BE INTERPOLATED BETWEEN SECTIONS ACCORDING TO SLOPE OF THE RECONFIGURED MOAB WASH.



SECTION R–R'

IMPOUNDMENT TOE PROTECTION DETAIL

(LOOKING NORTHWEST)



VERTICAL EXAGGERATION = 5X

RECONFIGURED MOAB WASH, IMPOUNDMENT TOE PROTECTION AND IMPOUNDMENT DRAINAGE CHANNEL CROSS SECTIONS

PREPARED FOR

ATLAS CORPORATION
DENVER, COLORADO

Canonie Environmental

No.	DATE	ISSUE NUMBER / REVISIONS	DWN. BY DATE	CK'D BY DATE	AP'D BY DATE
5	1-27-94	ISSUED TO COMPLY WITH NRC LICENSE CONDITION No. 4? NOT FOR CONSTRUCTION	P.W.W. 8-1-93	JWS 1-27-94	1-27-94
4	4-15-93	ISSUED FOR RESPONSE TO NRC COMMENTS	S.C.G. 4-8-93	J.M.C. 4-15-93	D.W.K. 4-15-93
3	6-5-92	ISSUED FOR REVISED RECLAMATION PLAN	R.M.S. 5-26-92	J.W.S. 6-3-92	D.W.K. 6-5-92
2	1-18-89	REVISED FOR RECLAMATION PLAN	R.H. 1-11-89	D.H.G. 1-16-89	D.P.W. 1-18-89
1	8-4-88	ISSUED AS ENGINEER'S REPORT RECLAMATION PLAN URANIUM MILL AND TAILINGS DISPOSAL AREA	R.H. 7-30-88	F.E.C. 8-4-88	D.P.W. 8-4-88

DATE:	7-23-88	SHEET 7 of 10	DRAWING NUMBER 88-067-E16	REV. 5
SCALE:	AS SHOWN			

9402240074-02

APPENDIX A

EROSION APRON DESIGN FOR THE SOUTHWEST DRAINAGE CHANNEL AND THE IMPOUNDMENT DRAINAGE CHANNEL

√JWS 4/13/93

B-1

TABLE OF CONTENTS

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By JMG Date 4-05-93 Subject Rock Apron Design Sheet No. 1 of 30

Chkd. By JWS Date 4-13-93 ATLAS MOAB MILL Project No. 88-067-10

PURPOSE:

Two surface water management channels will be constructed at the Atlas Corporation Moab, Utah mill to manage runoff from the reclaimed tailings impoundment. These channels are named as follows:

- Impoundment Drainage Channel
- Southwest Runoff Drainage Channel

The outlets of these channels must be protected from headcutting that may result from scour and propagate upstream, potentially impinging on tailings or buried debris. These outlets will be protected by rock cutoff walls. The purpose of this calculation brief is to state the design criteria and document the design procedures for the rock cutoff walls.

DESIGN CRITERIA:

The cutoff walls will be designed as follows:

- A buried cutoff wall constructed of riprap will be installed at the outlet of each channel. The total depth of flow will be managed in each channel until the point where the buried cutoff wall starts.
- Engineering controls end at the beginning of the buried cutoff wall. The depth of flow will no longer be maintained at this point.
- The design depth of the cutoff wall is equal to the calculated depth of scour. The wall will be constructed of riprap. The riprap will be placed at or less than the angle of repose for the riprap so that if a scour hole develops, the riprap will remain in-place (i.e not cave-in) and maintain protection against headcutting.
- The design width of the cut-off wall will be as wide as the calculated width of scour, or at least as wide as the plan view width of the channel.

- The nominal size (D50) of the riprap in each of the outlet channels will be maintained throughout each rock cutoff wall, respectively.

PROCEDURE:

The dimensions of the Lower Impoundment Drainage Channel and the Lower Southwest Runoff Channel were previously determined using either the Corp of Engineer's Method or the Safety Factor Method. For clarity, these spreadsheets have been enclosed as Sheets 5 and 6 of 30. The peak flow and cross-sectional area of flow from these spreadsheets are used in the scour calculation.

The grain size distribution of the Moab Wash soil is also needed to calculate scour. The grain size distributions of the Clean and Affected Moab Wash soils generated for radon barrier design were used to determine average gradation information.

Based on the configuration of each channel outlet and the gradation of the soil into which the channel discharges, the depth and width of scour can be calculated. The method used is documented on pages V-1 to V-11 of the Federal Highway Administration's (September 1983) "Hydraulic Design of Energy Dissipators for Culverts and Channels" (see Attachment A to this Calc. Brief). This method is recommended by NRC on page D-17 of the NRC's Staff Technical Position (see Reference #2).

The design depth and width of the buried cut-off wall is equal to the depth and width of scour calculated by the Federal Highway Administration's method. If design width is less than the channel plan view width, then the channel plan view width will be used to determine the width of the cutoff wall.

By JMG Date 4-05-93 Subject Rock Apron Design Sheet No. 3 of 30
Chkd. By JWS Date 4-13-93 ATLAS MOAB MILL Project No. 88-067-10

Results:

TABLE 1

Summary of Channel Outlet and Rock Cutoff Wall Characteristics

Channel / Reach	Channel Outlet Characteristics				Rock Cutoff Wall Characteristics		
	Bottom Width (ft)	Depth of Flow (ft)	x-sect Area of Flow (ft^2)	Plan Width[1] of Channel (ft)	Phi Angle[2] of Riprap (°)	Depth of Scour[3] (ft)	Width of Scour[3] (ft)
Impoundment Drainage Channel (Lower Reach)	25	3.53	125.63	46.18	42	8	48
Southwest Runoff Drainage Channel (Lower Reach)	50	2.25	127.69	63.5	42	8	64

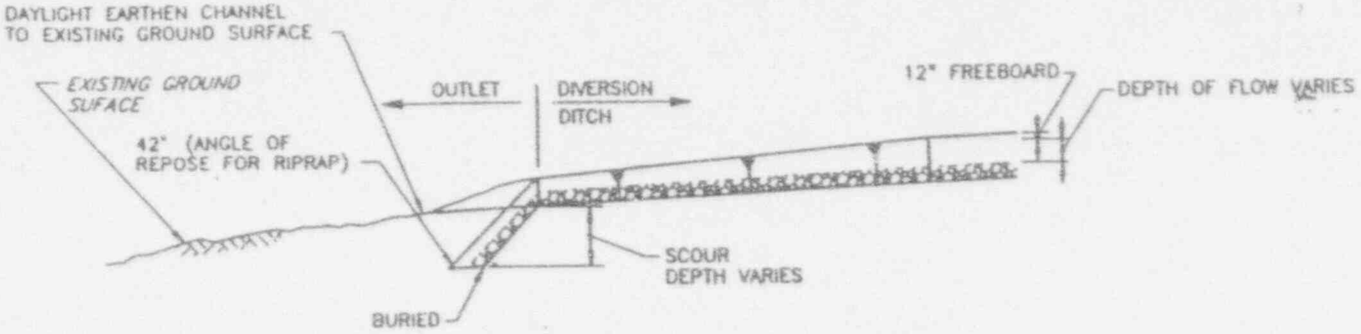
[1] Plan view width of channel is equal to bottom width plus six times depth of flow for a channel with 3H:1V sideslopes.

[2] Riprap Angle of Repose (phi) was taken from Surface Water Control Ditch Design Calculation, Atlas Minerals, by Canonie, 5/21/92 (submitted in the June 4, 1992 revised Atlas Reclamation Plan. Cutoff wall will be constructed at an angle less than this phi angle (approximately 40 degrees) to avoid collapse of the wall should a scour hole develop adjacent to the wall.

[3] Depth of Scour and Width of Scour calculated by the Federal Highway Administration Method were rounded up to the nearest foot to determine the dimensions of the wall. If the calculated width of scour was less than the width of the channel outlet, the width of the channel outlet was used.

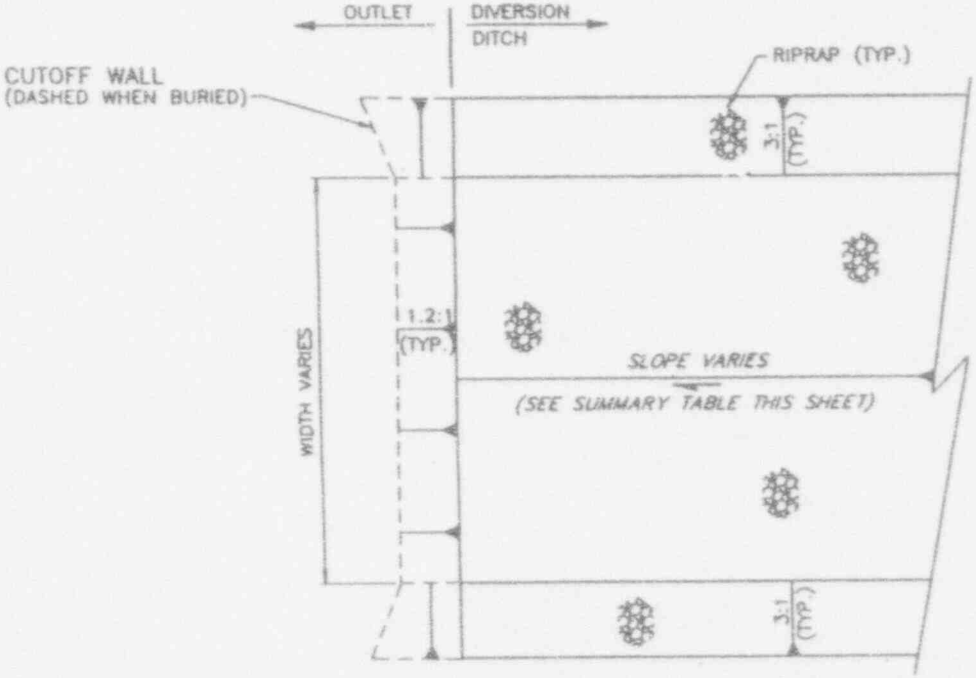
6-5

3A/30



PROFILE ROCK CUTOFF WALL
NOT TO SCALE

FIGURE 1.
Rock Cutoff Wall
Detail



PLAN
ROCK CUTOFF WALL
NOT TO SCALE

✓ SWJ 7/13/93

By JMG Date 4-05-93 Subject Rock Apron Design Sheet No. 4 of 30

Chkd. By JWS Date 4-13-93 ATLAS MOAB MILL Project No. 88-067-10

Channel Characteristics at the Outlet of the Impoundment Drainage Channel and the Southwest Runoff Channel

Using Safety Factor's Method or Corp of Engineer's Method

```
RIPRAP SIZE AND CHANNEL CONFIGURATION DESIGN BY CORPS. OF ENGINEERS METH

PROJECT:          Atlas Minerals
PROJECT #:        88-067-08
LOCATION:         LOWER IMPOUNDMENT DRAINAGE CHANNEL

INPUT PARAMETERS
****************

Q(input)        =     1640 CFS
BOTTOM WIDTH    =       25 FT
Z (SIDE SLOPE)  =        3 (ZH:1V)
CHANNEL SLOPE   =   0.0370 FT/FT
CHANNEL LENGTH  =      997 FT
FREEBOARD       =        1 FT
RIPRAP S.G.     =    2.47
RIPRAP DENSITY  =    154.1 LB/FT^3
THETA           =    42.00 Degrees


PHI             =    18.43 Degrees
ALFA            =     2.12 Degrees


 D50 (ASSUMED)  =     1.42 FT          <===
                     17.04 IN
            n   =    0.042
   d (ASSUMED)  =     3.53 FT          <===
            A   =   125.63 FT^2
            R   =     2.65 FT
     Q (CALC)   =   1644.1 CFS         Q(INPUT)    1640.0
ITERATE UNTIL Q(CALC) = Q(INPUT)

ACTUAL AVERAGE SHEAR STRESS ON RIPRAP
----------------------------------
AVG VEL OF FLOW=    13.09 FPS
AVERAGE SHEAR   =     4.58

ALLOWABLE RIPRAP SHEAR STRESS
----------------------------------
        BOTTOM  =     5.21
         SIDES  =     4.59
```

✓ JWS
4/13

B-8

C/CD JWS 4/13/93

6/30

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AP SIZE AND CHANNEL CONFIGURATION DESIGN BY SAFETY FACTOR METHOD    LSDCSF50.WR1

PROJECT:        Atlas Minerals                                    19-May-92
PROJECT #:      88-067-08                                          07:05 PM
LOCATION:       Lower Southwest Runoff Drainage Channel

INPUT PARAMETERS
****************

Q(input)        =    1723 CFS
BOTTOM WIDTH    =      50 FT
Z (SIDE SLOPE) =        3 (ZH:1V)
CHANNEL SLOPE  =  0.0750 FT/FT
CHANNEL LENGTH =      445 FT

RIPRAP S.G.     =    2.47
COEF FOR t      =    0.75         (See Reference; Figure 3.16, p. 192)
Phi             =   42.00 Degrees  (See Reference; Figure 3.14, p. 187)

SAFETY FACTORS METHOD
*********************

Alpha           =   18.43 Degrees
Theta           =    4.29 Degrees

     EL BOTTOM                              CHANNEL SIDE SLOPES
---------------                             -------------------

 D50 (ASSUMED) =     2.65 FT        (===    D50 (ASSUMED) =     2.65 FT       Avg. Riprap size    (===
             n  =   0.046                               n  =    0.046          Mannings n
  d (ASSUMED) =     2.25 FT        (===     d (ASSUMED)  =      2.25 FT       Depth of flow       (===
             A  =  127.69 FT^2                          A  =   127.69 FT^2     Area of flow
             R  =    1.99 FT                            R  =     1.99 FT       Hydraulic Radius
      Q (CALC)  =  1784.8 CFS                    Q (CALC)  =   1784.8 CFS      Check against Q(input)
             v  =   13.98 FPS                           v  =    13.98 FPS      Velocity
             t  =   10.53 PSF                        tMAX  =     7.90 PSF      Shear stress
          nu b =   0.910                             nu s =      0.68          See Reference

                                                    Beta  =    42.08 Degrees  See Reference

                                                     nu' =       0.59          See Reference

  SF (bottom)  =    1.00                    SF (sideslope)=     1.12          Safety Factor




---------------
REFERENCE:     'Applied Hydrology and Sedimentology for Disturbed Areas', pgs. 185-194, Barfield, Warner, and Haan

'(===' denotes variable parameters
```

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By JMG Date 4-05-93 Subject Rock Apron Design Sheet No. 7 of 30

Chkd. By JWS Date 4-13-93 ATLAS MOAB MILL Project No. 88-067-10

COMPUTE SCOUR DIMENSIONS

Compute Scour Dimensions

In order to determine the dimensions of scour by using the U.S. Federal Highway Administration (USFHA) method, coefficients of scour must be chosen using Table V-1 from page V-11 of Reference #1. These coefficients are chosen based on the gradation of the soil at the outlet of the channels (i.e., the material that is subject to scour).

A summary of the grain size distribution for the Moab Wash "Clean" and "Affected" soil are shown on sheets 14 and 15 of 30. These figures represent the average of all samples taken, and indicate 95% confidence intervals, maximums, and minimums. These figures were previously submitted in the Radon Barrier Cover Design Calculation, Appendix B (Sheet B-99) of the June 4, 1992 revised Atlas Reclamation Plan.

The following equation, taken from page V-2 of Reference #1, is used to assess whether the soil is uniform or graded:

S.D. = (d84/d16)^0.5, where S.D. is the standard deviation, d84, d16 are extracted from the grain size distribution.

If S.D. $\leq$ 1.5, then material is uniform.

If S.D. $\geq$ 1.5, then material is graded.

For the Moab Wash Clean and Affected soil, the average values of d84 and d16 are determined by interpolating from the plotted grain size distributions enclosed:

Clean Soil:	d84(ave) = 0.51 mm	
	d16(ave) = 0.06 mm	
Affected Soil:	d84(ave) = 1.35 mm	
	d16(ave) = 0.06 mm	

Therefore, using the USFHA equation above,

S.D.(Clean soil) = (0.51/0.06)^0.5 = 2.9
S.D. (Affected soil) = (1.35/0.06)^0.5 = 4.7

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Since S.D. is greater than 1.5, the Moab Wash soil is considered graded by the USFHA definition. The d50 (median grain size) of the Moab Wash Clean and Affected soil were also interpolated from the enclosed grain size distributions. d50 is fairly consistent between the Clean and Affected Moab Wash soils, and is interpolated to be 0.16 to 0.18 mm.

Given the properties of the Moab Wash soil as discussed above, the coefficients of scour are selected from Table V-1 of Reference #1. Given the catagories on Table V-1, the coefficients of scour for a graded sand with a d50 of 2.0mm best represent the Moab Wash soil. These coefficients will be used to compute the scour dimensions. The coefficients of scour are summarized in Table 3 on the following page.

A spreadsheet has been developed to calculate the scour dimensions based on the Federal Highway Administration Method in Reference #1. These spreadsheets are enclosed as Sheets 11 and 12 of 30, and indicate the calculated scour dimensions for each outlet.

A copy of Section V of the USFHA September 1983 document (Reference #1) has been enclosed as an attachment to this calculation brief.

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By JMG Date 4-05-93 Subject Rock Apron Design Sheet No. 10 of 30

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TABLE 3

Coefficients of Scour

	Alpha (e)	Beta	Theta
Depth of Scour	0.75	0.85	0.07
Width of Scour	4.78	0.76	0.06
Length of Scour	12.62	0.41	0.04
Volume of Scour	12.94	2.09	0.19

Given the coefficients of scour from Table 3 and the configuration of the end of the apron (see sheets 5 and 6 of 30), the dimensions of scour at this location are calculated using a spreadsheet. The results of these calculations are shown on sheet 11 of 30 for the Lower Impoundment Drainage Channel and Sheet 12 of 30 for the Lower Reach of the Southwest Runoff Drainage Channel.

√JWS 4/13/93

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SCOUR CALCULATIONS USING METHOD PRESENTED IN CHAPTER V OF U.S.D.O.T.'S HYDRAULIC CIRCULAR NO. 14 - HYDRAULIC DESIGN OF ENERGY DISSIPATORS FOR CULVERTS AND CHANNELS - (SEPTEMBER 1983)

ASSUME NON-CIRCULAR CULVERT (CHANNEL) WITH COHESIONLESS MATERIAL AT END OF CULVERT (i.e. LOCATION OF SCOUR)

ATLAS - MOAB, UTAH MILL   IMPOUNDMENT DRAINAGE CHANNEL OUTLET

1) INPUT PARAMETERS:

PMF FLOW (Q) = 1640 CFS (From HEC-1 Analysis of Channel)

AREA OF FLOW (A) = 125.63 FT^2 (From Ditch Design Spreadsheet)

PEAK FLOW DURATION (t1) = 30 MINUTES (Per method, assume 30 if not specified)

BASE TIME (t0) = 316 MINUTES (Per method, assume 316 if not specified)

2) CALCULATED PARAMETERS:

EQUIVALENT DEPTH (Ye) = 7.9 FT Ye = (A/2)^0.5

DISCHARGE INTENSITY (DI) = 1.63 DI = Q/((g)^0.5*(Ye)^2.5)
(where g = acceleration of gravity)

3) SELECT COEFFICIENTS OF SCOUR FROM TABLE V-1, (REFERENCE 1)

For a Graded Sand, d50 OF 2.0mm - Coefficients of Scour are:

	Alpha(e)	Beta	Theta
DEPTH OF SCOUR	0.75	0.85	0.07
WIDTH OF SCOUR	4.78	0.76	0.06
LENGTH OF SCOUR	12.62	0.41	0.04
VOLUME OF SCOUR	12.94	2.09	0.19

(FROM TABLE V-1, REFERENCE #1)

4) CALCULATE SCOUR DIMENSIONS:

DEPTH (Hs) = 7.7 FT

WIDTH (Ws) = 47.8 FT

LENGTH (Ls) = 111.3 FT

VOLUME (Vs) = 11497.8 FT^3

Dimensions calculated by the formula:

Dimension / Ye = alpha*(DI)^beta*(t1/t0)^theta

by entering appropriate scour coefficients.

LOCATION OF MAXIMUM SCOUR = 44.5 FT DOWNSTREAM OF THE END OF THE CHANNEL
(Location = 0.4*Ls)

√ 4/13/93

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SCOUR CALCULATIONS USING METHOD PRESENTED IN CHAPTER V OF U.S.D.O.T.'S HYDRAULIC CIRCULAR NO. 14 - HYDRAULIC DESIGN OF ENERGY DISSIPATORS FOR CULVERTS AND CHANNELS - (SEPTEMBER 1983)

ASSUME NON-CIRCULAR CULVERT (CHANNEL) WITH COHESIONLESS MATERIAL AT END OF CULVERT (i.e. LOCATION OF SCOUR)

ATLAS - MOAB, UTAH MILL SOUTHWEST RUNOFF DRAINAGE CHANNEL OUTLET

1) INPUT PARAMETERS:

PMF FLOW (Q) = 1723 CFS (From HEC-1 Analysis of Channel)

AREA OF FLOW (A) = 127.69 FT^2 (From Ditch Design Spreadsheet)

PEAK FLOW DURATION (t1) = 30 MINUTES (Per method, assume 30 if not specified)

BASE TIME (t0) = 316 MINUTES (Per method, assume 316 if not specified)

2) CALCULATED PARAMETERS:

EQUIVALENT DEPTH (Ye) = 8.0 FT Ye = (A/2)^0.5

DISCHARGE INTENSITY (DI) = 1.68 DI = Q/((g)^0.5*(Ye)^2.5)
(where g = acceleration of gravity)

3) SELECT COEFFICIENTS OF SCOUR FROM TABLE V-1, (REFERENCE 1)

For a Graded Sand, d50 OF 2.0mm - Coefficients of Scour are:

	Alpha(e)	Beta	Theta
DEPTH OF SCOUR	0.75	0.85	0.07
WIDTH OF SCOUR	4.78	0.76	0.06
LENGTH OF SCOUR	12.62	0.41	0.04
VOLUME OF SCOUR	12.94	2.09	0.19

(FROM TABLE V-1, REFERENCE #1)

4) CALCULATE SCOUR DIMENSIONS:

DEPTH (Hs) = 7.9 FT

WIDTH (Ws) = 49.2 FT

LENGTH (Ls) = 113.6 FT

VOLUME (Vs) = 12519.0 FT^3

Dimensions calculated by the formula:

$$\frac{\text{Dimension}}{\text{Ye}} = \text{alpha*(DI)^beta*(t1/t0)^theta}$$

by entering appropriate scour coefficients.

LOCATION OF MAXIMUM SCOUR = 45.4 FT DOWNSTREAM OF THE END OF THE CHANNEL
(Location = 0.4*Ls)

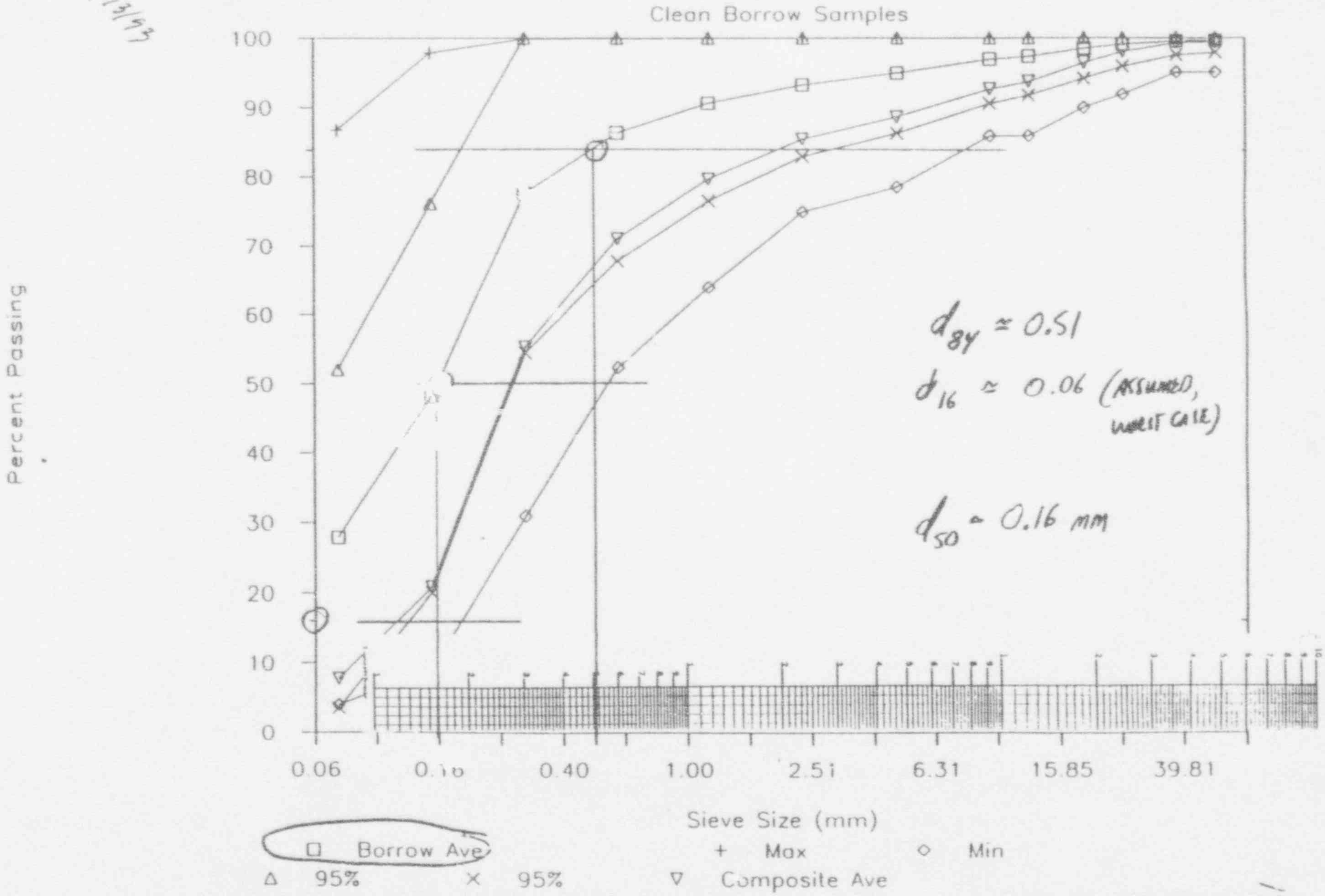
GRAIN SIZE DISTRIBUTIONS

FOR SAMPLES OF

MOAB WASH "CLEAN" AND "AFFECTED" SOIL

√ JWS
4/13/93

Figure 2


Clean Borrow Samples

$d_{84} \approx 0.51$

$d_{16} \approx 0.06$ (ASSUMED, WORST CASE)

$d_{50} \approx 0.16$ mm

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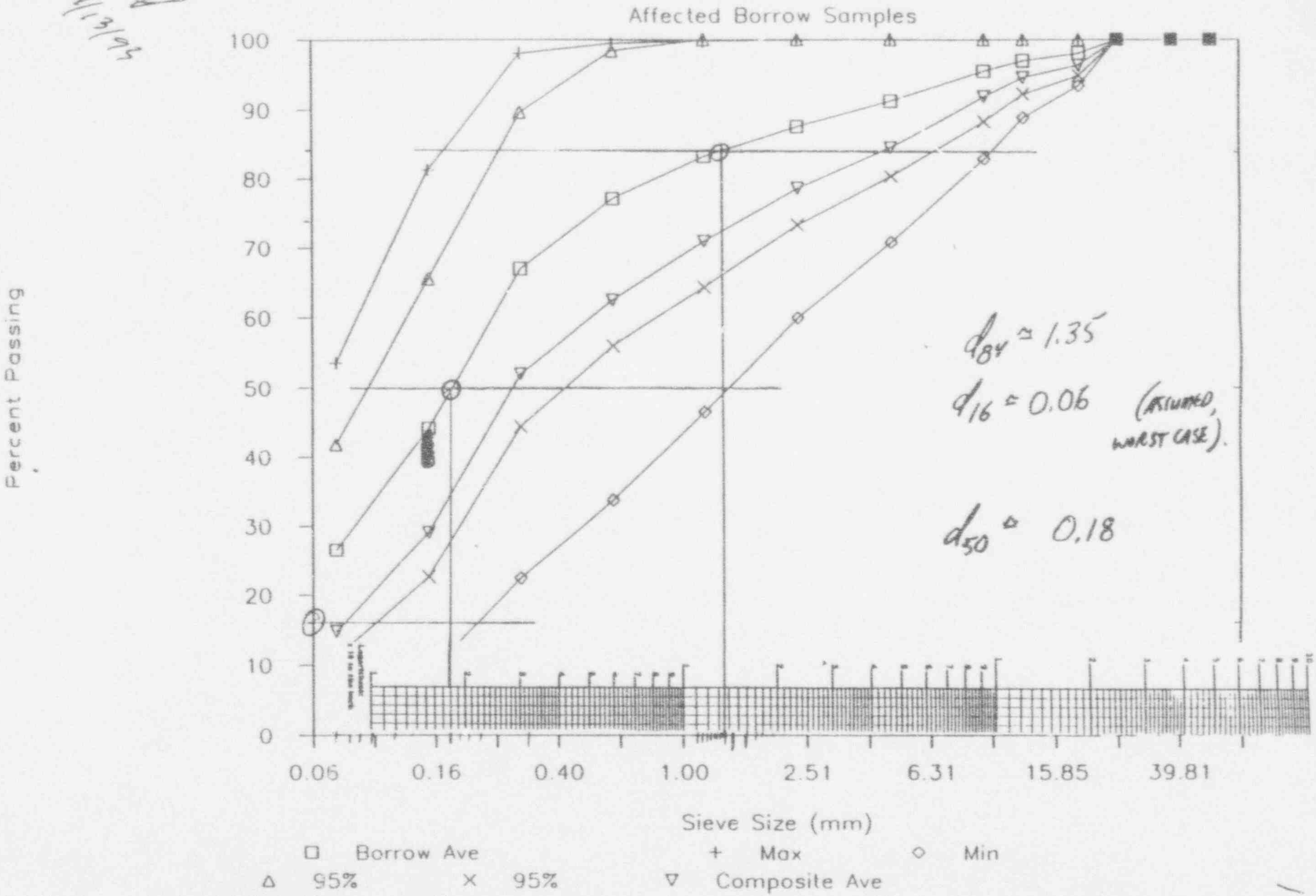
Figure 3



$d_{84} \simeq 1.35$

$d_{16} \simeq 0.06$ (ASSUMED, WORST CASE).

$d_{50} \simeq 0.18$

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Chkd. By JWS Date 4/13/93 ATLAS MOAB MILL Project No. 88-067-10

REFERENCES

By JMG Date 4-05-93 Subject Rock Apron Design Sheet No. 17 of 30

Chkd. By JWS Date 4-13-93 ATLAS MOAB MILL Project No. 88-067-10

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ATTACHMENT A

EXCERPTS FROM "HYDRAULIC DESIGN OF ENERGY DISSIPATORS FOR CULVERTS AND CHANNELS,"

U.S. FEDERAL HIGHWAY
ADMINISTRATION, SEPTEMBER 1983

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19/30

PB86-180205

Hydraulic Design of Energy Dissipators for Culverts and Channels

(U.S.) Federal Highway Administration
Washington, DC

Sep 83

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CHAPTER V

ESTIMATING EROSION AT CULVERT OUTLETS

Estimating erosion at culvert outlets is difficult because of the many complex factors affecting erosion. Some of these factors are the discharge, culvert diameter, soil type, duration of flow and tailwater depth. In addition, the magnitude of the total erosion can consist of local scour and channel degradation, the two types of erosion discussed in Chapter II-B. Maintenance history, site reconnaissance and data on soils, flows and flow duration provide the best estimate of the potential erosion hazard at a culvert outlet.

The objective of this chapter is to present a method for predicting local scour at the outlet of structures based on soil and flow data and culvert geometry. This scour prediction is intended to serve together with the maintenance history and site reconnaissance information for determining energy dissipator needs.

Investigations (1), (3), indicate that the scour hole geometry varies with tailwater conditions with the maximum scour geometry occuring at tailwater depths less than half the culvert diameter (1); and that the maximum depth of scour (h_s) occurs at a location approximately 0.4 L_s downstream of the culvert outlet (3) where L_s is the length of scour.

Empirical equations defining the relationship between the culvert discharge intensity, time, and the length, width, depth, and volume of scour hole are presented for the maximum or extreme scour case.

Cohesionless Material

The general expression for determining scour geometry in a cohesionless soil for a circular pipe flowing full is

$$\text{Dimensionless Scour Geometry} = \alpha \left(\frac{Q}{\sqrt{g}\, D^{5/2}}\right)^{\beta} \left(\frac{t}{t_o}\right)^{\theta} \qquad \text{(V-1)}$$

where:

Dimensionless Scour Geometry is $\frac{h_s}{y_e}$, $\frac{W_s}{y_e}$, $\frac{L_s}{y_e}$, or $\frac{V_s}{y_e}$

h_s, W_s, L_s, and V_s are depth, width, length and volume of scour respectively.

D is the diameter of the culvert

Q is the discharge, g is the acceleration of gravity

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t is the time in minutes

t_o is a base time used in the experiments to derive coefficients (316 minutes unless specified otherwise).

For noncircular or part full culverts, the diameter D can be replaced by a n equivalent depth y_e, where y_e is defined as

$$y_e = (A/2)^{1/2}$$

and A is the cross sectional area of flow. Modifying Equation (V-1) to include the equivelent depth results in the general expression.

$$\text{Dimensionless Scour Geometry} = \alpha_e\left(\frac{Q}{\sqrt{g}\,y_e^{5/2}}\right)^{\beta}\left(\frac{t}{t_o}\right)^{\theta} \qquad \text{(V-2)}$$

where:

$\alpha_e = \simeq 0.63^{2.5\beta-1}$ for h_s, W_s, and L_s

$\alpha_e = \alpha\,0.63^{2.5\beta-3}$ for V_s

The values of the coefficients α_e, β, and θ in Equations V-1 and V-2 are given in Table V-1.

Gradation

The cohensionless bed materials presented in Table V-1 are categorized as either uniform (U) or graded (G). The grain size distribution is determined by performing a sieve analysis (ASTM DA22-63). The standard deviation (σ) is computed as:

$$\sigma = \left(\frac{d_{84}}{d_{16}}\right)^{1/2}$$

where the values of d_{84} and d_{16} are extracted from the grain size distribution. If ≤ 1.5, the material is considered to be uniform; if ≥ 1.5, the material is classified as graded.

Cohesive Soils

If the cohesive soil is a sandy clay similar to the one tested at Colorado State niversity by Abt et al (8), Equation (V-1) or (V-2) and the appropriate coefficients in Table V-1 can be used to estimate the scour hole dimensions. The sandy clay tested had 58 percent sand, 27 percent clay, 15 percent silt and percent organic matter; had a mean grain size of 0.15 mm and had a plasticity ndex, PI, of 15.

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Since Equations V-1 and V-2 do not include soil characterisitcs, they can only be used for soils similar to the ones tested. Shear number expressions, that related scour to the critical shear stress of the soil, were derived to have a wider range of applicability for cohesive soils besides the one specific sandy clay that was tested. The shear number expressions for circular culverts are:

$$\left[\frac{h_s}{D}, \frac{W_s}{D}, \frac{L_s}{D}, \text{ or } \frac{V_s}{D}\right] = \alpha\left(\frac{\rho V^2}{\tau_c}\right)^{\beta}\left(\frac{t}{t_o}\right)^{\theta} \qquad \text{(V-3)}$$

and for other shaped culverts:

$$\left[\frac{h_s}{y_e}, \frac{W_s}{y_e}, \frac{L_s}{y_e}, \text{ or } \frac{V_s}{y_e}\right] = \alpha_e\left(\frac{\rho V^2}{\tau_c}\right)^{\beta}\left(\frac{t}{t_o}\right)^{\theta} \qquad \text{(V-4)}$$

where: $\frac{\rho V^2}{\tau_c}$ is the modified shear number

V = outlet mean velocity

τ_c = critical tractive shear stress

ρ = fluid density

$\alpha_e = \frac{\alpha}{.63}$ for h_s, W_s, and L_s

$\alpha_e = \frac{\alpha}{(.63)^3}$ for V_s

The values of the coefficients α, β, θ, and α_e in Equations V-4 and V-5 are presented in Table V-1. The critical tractive shear stress (2) is defined as

$$\tau_c = 0.0001\,(S_v + 180)\tan(30 + 1.73\,PI) \qquad \text{(V-5)}$$

where S_v is the saturated shear strength in pounds per square inch and PI is the Plasticity Index from the Atterberg Limits.

It is recommended that Equations V-3 and V-4 be limited to sandy clay soils with a plasticity index of 5-16.

Time of Scour

The time of scour is estimated based upon a knowledge of peak flow duration. Lacking this knowledge, it is recommended that a time of 30 minutes be used in Equations V-1, V-2, V-3, and V-4. The tests indicate that approximately 2/3 to 3/4 of the maximum scour occurs in the first 30 minutes of the flow duration.

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It should be noted that the exponents for the time parameter in Table V-1 reflect the relatively flat part of the scour-time relationship and are not applicable for the first 30 minutes of the scour process.

Headwalls

Installation of headwalls (6) flush with the culvert outlet moves the scour hole downstream. However, the magnitude of the scour geometries remain essentially the same as for the case without the headwall. If the culvert is installed with a headwoll, the headwall should extend to a depth equal to the maximum depth of scour.

SUMMARY

The prediction equations presented in this chapter are intended to serve along with field reconnaissance as guidance for determining the need for energy dissipators at culvert outlets. It should be remembered that the equations do not include long-term channel degradation of the downstream channel. The equations are based on tests which were conducted to determine maximum scour for the given condition and therefore represent what might be termed worst case scour geometries. The equations were derived from tests conducted by the Corps of Engineers (1), and Colorado State University (5), (6), (7), (8) and (9).

B-2t

Design Procedure

1. Perform a hydrologic analysis of the drainage in which the culvert is located or to be placed. Estimate the magnitude and duration of the peak discharge. Express the discharge in cfs and the duration in minutes.

The discharge intensity is

$$\text{D.I.} = \frac{Q}{\sqrt{g}\,D^{5/2}} \text{ for circular culverts flowing full}$$

$$\text{D.I.} = \frac{Q}{\sqrt{g}\,y_e^{5/2}} \text{ for other shapes}$$

where $y_e = \left(\frac{A}{2}\right)^{1/2}$

FOR COHESIONLESS MATERIALS, OR THE 0.15mm SANDY CLAY

2. Compute the discharge intensity when the culvert is flowing at the peak discharge.

3. Determine scour coefficients from Table V-1.

4. Compute the scour hole dimensions from

$$\left[\frac{h_s}{D}, \frac{W_s}{D}, \frac{L_s}{D}, \text{ or } \frac{V_s}{D^3}\right] = \alpha\left(\frac{Q}{\sqrt{g}\,D^{5/2}}\right)^{\beta}\left(\frac{t}{316}\right)^{\theta} \qquad \text{(V-1)}$$

or

$$\left[\frac{h_s}{y_e}, \frac{W_s}{y_e}, \frac{L_s}{y_e}, \text{ or } \frac{V_s}{y_e}\right] = \alpha_e\left(\frac{Q}{\sqrt{g}\,y_e^{5/2}}\right)^{\beta}\left(\frac{t}{316}\right)^{\theta} \qquad \text{(V-2)}$$

FOR OTHER COHESIVE MATERIALS WITH PI FROM 5 TO 16

a. Compute the culvert outlet velocity in feet/sec.

b. Obtain a soil sample at the proposed culvert location.

c. Perform Atterberg limits tests and determine the plasticity index, PI (ASTM D423-36).

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d. Saturate a sample and perform an unconfined compressive test (ASTM D211-66-76) to determine the saturated shear stress, Sv, in pounds per square inch.

e. Compute the critical tractive shear strength, τ_c, from equation V-5.

f. Compute the modified shear number $\frac{\rho V^2}{\tau_c}$

3. Determine scour coefficients from Table V-1.

4. Compute the desired scour hole dimensions from

$$\left[\frac{h_s}{D}, \frac{W_s}{D}, \frac{L_s}{D}, \text{ or } \frac{V_s}{D}\right] = \alpha \left(\frac{V^2}{\tau_c}\right)^{\beta} \left(\frac{t}{316}\right)^{\theta}$$

for circular culvert

or

$$\left[\frac{h_s}{y_e}, \frac{W_s}{y_e}, \frac{L_s}{y_e}, \frac{V_s}{y_e^3}\right] = \alpha_e \left(\frac{V^2}{\tau_c}\right)^{\beta} \left(\frac{t}{316}\right)^{\theta}$$

for noncircular culverts.

Example Problem Cohesionless Material

Determine the scour geometry--maximum depth, width, length and volume of scour--for a proposed circular 30-inch C.M.P. discharging an estimated 50 cfs when flowing full. The downstream channel is composed of a graded gravel material.

1. The duration of the peak discharge of 50 cfs is not known. Therefore, a peak flow duration of 30 minutes will be estimated.

2. The circular, 30-inch C.M.P. at 50 cfs will have a discharge intensity of

$$\text{D.I.} = \frac{50}{\sqrt{g}\,\frac{(30)^{5/2}}{12}} = \frac{50}{(5.67)(2.5)^{5/2}} = 0.89$$

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3. The coefficients of scour obtained from Table V-1 are:

	α	β	θ
Depth of Scour	1.49	.50	.03
Width of Scour	8.76	0.89	.10
Length of Scour	13.09	0.62	.07
Volume of Scour	42.31	2.28	.17

4. Scour hole dimensions:

depth: $\frac{h_s}{D} = \alpha\left(\frac{Q}{\sqrt{g}\, D^{2.5}}\right)^{\beta}\left(\frac{t}{316}\right)^{\theta}$

$= 1.49\ (0.89)^{0.50}\ (0.09)^{.03}$; $h_s = 3.27$ ft

width: $\frac{W_s}{D} = 8.76(0.89)^{0.89}\ (.09)^{.10}$; $W_s = 15.5$ ft

Length: $\frac{L_s}{D} = 13.09(0.89)^{0.62}\ (.09)^{.07}$; $L_s = 25.72$ ft

Volume: $\frac{V_s}{D^3} = 42.31(0.89)^{2.28}\ (.09)^{.17}$; $V_s = 335.79\ ft^3$

5. The location of the maximum scour (Figure V-2)

$0.4\ (L_s) = .4\ (25.72) = 10.3$ ft downstream of the culvert outlet.

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Example Problem Cohesive Material

Determine the scour geometry-maximum depth, width, length and volume of scour for an existing circular 24-inch C.M.P. discharging an estimated 40 cfs when flowing full. The downstream channel is composed of a sandy-clay material.

1. The duration of the peak discharge of 40 cfs is not known. Therefore, a peak flow duration of 30 minutes will be estimated.

2. a. The average velocity at the culvert outlet is:

$$V = \frac{Q}{A} = \frac{40.0}{3.14} = 12.74 \text{ fps}$$

b-e. The sandy-clay material was tested and found to have a Plasticity Index (PI) of 12 and a saturated shear strength (Sv) of 240 psi.

The critical tractive shear can be estimated by substituting into Equation V-

$$_c = 0.001 (240 + 180) \tan (30 + 1.73(12))$$

$$0.001(420) \tan (50.76) = 0.51 \text{ lb/ft}^2$$

f. The modified shear number $S_{n_{mod}} = \frac{(\rho V^2)}{\tau_c}$ is:

$$S_{n_{mod}} = \frac{1.94 (12.74)^2}{0.51} = 617.4$$

3. The experimental coefficients α, β and θ from Table V-1 are

	α	β	θ
Depth	.86	.18	.10
Width	3.55	.17	.07
Length	2.82	.33	.09
Volume	.62	.93	.23

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4. The scour hole dimensions are:

$$\frac{h_s}{D} = \alpha \left(\frac{\rho V^2}{\tau_c}\right)^{\beta} \left(\frac{t}{316}\right)^{\theta}$$

$$= .86(617.4)^{.18} (.09)^{.10}; \quad h_s = 2.14 \text{ X } 2 \quad = 4.30 \text{ ft}$$

$$\frac{W_s}{D} = 3.55(617.4)^{.17} (.09)^{.07}; \; W_s = 8.94 \text{ X } 2 = 27.9 \text{ ft}$$

$$\frac{L_s}{D} = 2.82(617.4)^{.33} (.09)^{.09}; \; L_s = 18.92 \text{ X } 2 = 37.8 \text{ ft}$$

$$\frac{V_s}{D^3} = .62(617.4)^{.93} (.09)^{.23}; \; V_s = 140.3 \text{ X } 23 \quad = 1122.5 \text{ ft}^3$$

5. Location of maximum depth of scour (Figure V-2)

$0.4\ L_s = 0.4(37.8) = 15.1$ ft downstream of culvert outlet

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Table V-1. Experimental Coefficients for Culvert Outlet Scour

MATERIAL	NOMINAL GRAIN SIZE d_{50} (mm)	SCOUR EQUATION	DEPTH h_s				WIDTH W_s				LENGTH L_s				VOLUME V_s			
			α	β	θ	α_e	α	β	θ	α_e	α	β	θ	α_e	α	β	θ	α_e
Uniform Sand	0.20	V-1 or V-2	2.72	.375	0.10	2.79	11.73	0.92	.15	6.44	16.82	0.71	0.125	11.75	203.36	2.0	0.375	80.71
Uniform Sand	2.0	V-1 or V-2	1.66	0.45	0.09	1.76	8.44	0.57	0.06	6.94	18.28	0.51	0.17	16.10	101.48	1.41	3.34	79.62
Graded Sand	2.0	V-1 or V-2	1.22	0.85	0.07	.75	7.25	0.76	0.06	4.78	12.77	0.41	0.04	12.62	36.17	2.09	0.19	12.94
Uniform Gravel	8.0	V-1 or V-2	1.78	0.45	0.04	1.68	9.13	0.62	0.08	7.08	14.36	0.95	0.12	7.61	65.91	1.86	0.19	12.15
Graded Gravel	8.0	V-1 or V-2	1.49	0.50	0.03	1.33	8.76	0.89	0.10	4.97	13.09	0.62	0.07	10.15	42.31	2.28	0.17	32.82
Cohesive Sandy Clay 60% Sand PI 15	0.15	V-1 or V-2	1.86	0.57	0.10	1.53	8.63	0.35	0.07	9.14	15.30	0.43	0.09	14.78	79.73	1.42	0.23	61.81
Clay PI 5-16	Various	V-3 or V-4	0.86	0.18	0.10	1.37	3.55	0.17	0.07	5.63	2.82	0.33	0.09	4.48	0.62	0.93	0.21	2.48

EQUATIONS:

V-1. FOR CIRCULAR CULVERTS. Cohesionless material or the 0.15mm cohesive sandy clay

$$\left[\frac{h_s}{D}, \frac{W_s}{D}, \frac{L_s}{D}, \text{ or } \frac{V_s}{D^3}\right] = \alpha\left(\frac{Q}{\sqrt{g}\,D^{5/2}}\right)^{\beta}\left(\frac{t}{t_o}\right)^{\theta}$$

where t_o = 316 min.

V-2. FOR OTHER CULVERTS SHAPES. Same material as above.

$$\left[\frac{h_s}{y_e}, \frac{W_s}{y_e}, \frac{L_s}{y_e}, \text{ or } \frac{V_s}{y_e^3}\right] = \alpha_e\left(\frac{Q}{\sqrt{g}\,y_e^{5/2}}\right)^{\beta}\left(\frac{t}{t_o}\right)^{\theta}$$

where t_o = 316 min.

V-3. FOR CIRCULAR CULVERTS. Cohesive sandy clay with PI = 5-16

$$\left[\frac{h_s}{D}, \frac{W_s}{D}, \frac{L_s}{D}, \text{ or } \frac{V_s}{D^3}\right] = \alpha\left(\frac{\rho V^2}{\tau_c}\right)^{\beta}\left(\frac{t}{t_o}\right)^{\theta}$$

where: t_o = 316 min.

V-4. FOR OTHER CULVERT SHAPES. Cohesive sandy clay with PI = 5-16

$$\left[\frac{h_s}{y_e}, \frac{W_s}{y_e}, \frac{L_s}{y_e}, \text{ or } \frac{V_s}{y_e^3}\right] = \alpha_e\left(\frac{\rho V^2}{\tau_c}\right)^{\beta}\left(\frac{t}{t_o}\right)^{\theta}$$

where: t_o = 316 min.

APPENDIX B

MOAB WASH CHANNEL BANK EROSION PROTECTION DESIGN CALCULATION BRIEF

MOAB WASH CHANNEL BANK AND NORTHEAST DEBRIS PIT EROSION PROTECTION

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Purpose and Background. The purpose of this calculation brief is to determine the size and quantity of riprap to protect the tailings embankment of the Atlas Uranium Tailings Impoundment in Moab Utah from a potential encroachment by the Moab Wash. Figure 1 (sheet 24) shows a plan view of the Tailings Impoundment and Moab Wash at the Atlas Site in Moab, Utah. Figure 2 shows several cross sections along the Moab Wash.

Also, as part of this calculation brief, erosion protection will be designed for the Northeast Debris Pit located adjacent to the toe of the reclaimed disposal area. Erosion protection will be designed to protect the pit from Moab Wash flows and from runoff from the 10:3 embankment outslope.

The U.S. Nuclear Regulatory Commission (NRC) believes that the inner channel of the Moab Wash may meander over to the base of the 10:3 slope of the tailing's embankment during the 1000 year design period as indicated on the sketch in Figure 3. To prevent encroachment upon the tailings from scouring of the Moab Wash, additional riprap protection along the southern bank of the Moab Wash at the edge of the tailings embankment will be designed as shown on Figure 3.

Riprap to protect the Northeast debris pit from the Moab Wash flows will be placed at the end of 1 % slope as indicated on Figure 4. To protect the pit from runoff from the 10:3 embankment, riprap will be placed on top of the debris pit from the base of the 10:3 slope to the start of the 3:1 slope as indicated on Figure 4.

Important assumptions in the design calculations that follow are:

- The meandered channel configuration as sketched on the cross sections in Figure 2 has the same channel invert elevation, Probable Maximum Flow (PMF), Depth at PMF, and channel width as the original channel.

Additionally, as seen from Figure 1, encroachment of the Moab Wash upon the tailing's embankment is most likely from section L-L' to N-N' because the cutting edge (outside bank of a bend) of Moab Wash is towards the tailings. However, after section N-N', the Moab Wash and the impoundment are configured such that the erosion will occur on the opposite side of the Moab Wash channel. Conversely, deposition will occur along the tailings impoundment east of section N-N'. As a precautionary measure, riprap protection will be extended past section N-N' to the limits of the reconfigured Moab Wash and then along the 3:1 side slope of the Moab Wash limit to the end of the Northeast Debris Pit as indicated on Figure 1. However, the remaining portion of the tailings will not be projected, and the analysis of potential erosion of the east bank of the impoundment by the Colorado River and the Moab Wash provided in the Atlas Corp. Reclamation Plan (Canonie, 1992) remains valid.

Results. Table 7a (SHEET 22) summarizes scour depth, riprap invert elevation ,and riprap top elevation for the Moab Wash Channel Bank protection. Table 7b (sheet 22) summarizes the riprap width, riprap length, riprap mean grain size, riprap layer thickness, volume of riprap, and volume of filter material for the Moab Wash channel bank protection and Northeast debris pit erosion protection. Figure 3 shows the Moab Wash channel bank protection for the riprap placed at the base of the regraded tailings 10:3 embankment from section L-L' to the beginning of the Northeast Debris pit as shown on Figure 1. Figure 4 shows the Northeast Debris pit riprap for erosion protection from runoff from the 10:3 embankment slope and from Moab Wash flows.

Method. The method for determining the size of the riprap protection to protect the embankment from Moab Wash flows, the method for determining the riprap to protect the Northeast debris pit, and the method for determining the depth of scour and required volume of riprap are discussed below. In summary, the following approach will be used:

- Riprap D_{50} size required to protect against Moab Wash PMF flows are determined based on hydraulic properties at sections L-L', M-M', N-N', and P-P' (See Figure 1) using the Corp of Engineers (allowable local shear stress) method. Conservative assumptions are used such as average channel velocities (in lieu of channel bank velocities) and supercritical flow conditions (resulting in higher velocities).
- Riprap gradation and filter requirements are determined from the D_{50} sizes calculated.
- Protection of the impoundment toe and Moab Wash Channel toe is evaluated.
- Overland flow analysis is performed to determine required riprap over the proposed Northeast Debris pit to protect from runoff from the 10:3 embankment.
- Scour depth is evaluated at the impoundment toe at sections L-L', M-M', N-N', and P-P' (See Figure 1).
- The configuration of the Moab Wash/Impoundment toe erosion protection is determined by:
    - extending a buried rock wall to the maximum depth of scour, and completing the wall at 1.0' above Moab Wash subcritical (conservative) PMF water elevation. (see Figures 3 and 4)
    - Providing additional protection of the impoundment toe by designing a horizontal component at the base of the buried rock wall.
- The volume of Moab Wash and Northeast debris pit riprap protection is determined.

1. Channel Bank Riprap. To determine the size of riprap required to protect the tailings from Moab wash flows, the Corps of Engineers (COE) method (EM-1110-2-1601, 1970) is used to size the riprap. Attachment A (Sheet 30) contains excerpts from EM-1110-2-1601. The COE method compares the local shear stress over a channel cross section to an allowable channel bottom shear stress and an allowable channel side shear stress. The local shear, τ_o, is:

$$\tau_o=\frac{\gamma\overline{V^2}}{(32.6LOG_{10}12.2\frac{Y}{D_{50}})^2}$$

where

V = Avg. local velocity, ft/s.

Y = depth of flow, ft.

D_{50} = Riprap mean grain size diameter, ft.

The equations describing the allowable bottom and side shear are:

$$\tau=a(\gamma_s-\gamma_w)D_{50}$$

$$\tau'=\tau(1-\frac{\sin^2\phi}{\sin^2\theta})^{0.5}$$

where

τ = bottom shear stress, psf

τ' = side shear stress, psf

a = constant = 0.04

γ_s = unit weight of riprap, = 154.1 pcf, using specific gravity of 2.47

γ_w = unit weight of water = 62.4 pcf

ϕ = side slope angle of channel = $\tan^{-1}$ (3/10) = 16.7° (10:3 slope)

θ = angle of repose of riprap = 42°

For specific gravity and riprap repose angle reference see Surface Water Control Calculations, Atlas Corporation Reclamation Plan (Canonie, June 1992), Appendix D.

For a given channel configuration, a D_{50} (mean grain size) is chosen and the shear stress equations are solved. A new D_{50} is chosen until the actual shear stress is less than the allowable shear stress. Table 1 (sheet 15) presents the results from COE method for sections L-L', M-M', N-N', and P-P' along the Moab Wash. Depth of flow and main channel velocity (taken as the average local velocity) are from the HEC-2 Moab Wash supercritical run performed for the Atlas Corporation Reclamation Plan (Canonie, June 1992). The output from the Moab Wash HEC-2 supercritical run has been included as Attachment B. Sections L-L', M-M', N-N', and P-P' roughly correspond to sections 6, 5, 4, and 2 respectively in the HEC-2 run provided in Attachment B. Supercritical velocities are greater than subcritical velocities and supercritical depths are slightly smaller than subcritical depths resulting in a greater local shear stress and more conservative D_{50} size. Figure 1 shows the location of the approximate sections.

A. Riprap Gradation Analysis

The D_{50} sizes range from 2.4" to 8.8". These are raw D_{50} (not oversized) and need to be oversized for durability by 2 % (see Rock Quality - Assessment of Oversizing Requirements, Atlas Corp. Reclamation Plan (Canonie, June 1992), Appendix E).

Moab Wash Sections L-L', M-M', and N-N'. To minimize the number of riprap gradations, the riprap for the Moab Wash channel bank protection for sections L-L', M-M, and N-N' will be grouped into one single gradation with a largest raw D_{50} of 8.8" calculated for section L-L'. With 2% oversizing, the necessary d_{50} for the gradation is:

$$1.02 \times 8.8" = 9.0 \text{ inches.}$$

Since no riprap gradations exist for a D_{50} of 9" in the reclamation design submitted in the Atlas Corp. Rec. Plan (Canonie, June 1992), a new riprap gradation must be developed. The same procedure followed in the Atlas Corp. Rec. Plan (Canonie, June 1992) will be followed to develop the gradation. The D_{50} sizes for the Moab Wash sections were designed under supercritical conditions (i.e. Froude Number > 1). Therefore, according to Simons (1982):

$$Dmax = 1.25 \times D_{50} = 1.25 \times 9 = 11.25\ "$$

$$D_{20} = D_{50}/2 = 4.5"$$

$$D_{10} = D_{50}/3 = 3"$$

Using these values, a lower limit riprap gradation curve is developed (see Figure 5 (sheet 28)). To provide flexibility during construction, a range of particle sizes for the gradation is developed by sketching an upper limit curve. NUREG 4651 recommends that the uniformity coefficient, C_u, of the riprap envelope be ≥ 1.75 to maintain a well graded riprap layer. The upper limit curve is sketched on Figure 5 and the gradation requirement is summarized on Table 2 (sheet 16). The thickness of this riprap layer is:

$$1.5 \times D_{50} = \underline{13.5"} \text{ (NRC, Final STP, 1990 for } D_{50} > 8")$$

Moab Wash Section P-P'. For riprap designed according to section P-P' (see Figure 1 for the location of this riprap), with a raw D_{50} of 2.4" , alluvial cobbles will be used because the raw D_{50} is less than 3". Riprap from the rock borrow source of the alluvial cobbles must be oversized 15% for durability and 20 % for roundness (see

Atlas Corp. Rec. Plan (Canonie, June 1992), Appendix E for oversizing specifications). The necessary D_{50} is therefore:

$$2.4" (1.15) \times (1.20) = \underline{3.3"}$$

To limit the number of riprap gradations, the riprap gradation developed in the Atlas Corp. Rec. Plan (Canonie, June 1992) for the Collection Ditches, 10:3 Embankment, and 10:1 Embankment with a necessary D_{50} 4.1 inches will be used for section P-P'. The gradation requirement is summarized in Table 2. The riprap layer thickness is:

$$2 \times D_{50} \cong \underline{8"} \quad (\text{NRC, 1990 for } D_{50} < 8")$$

This riprap is designed to protect the Northeast Debris Pit from Moab Wash Flows. See item 2 below for the design of riprap protection from runoff from the 10:3 embankment.

B. Toe Protection

To provide additional protection at the toe of the channel protection from Moab Wash flows, riprap is extended 5 times the riprap layer thickness horizontally from the base of the channel protection. This distance from the toe is recommended in EM-1110-2-1601 (US COE, 1991) (See Attachment A for excerpts). For Moab Wash riprap protection corresponding to sections L-L', M-M', and N-N', which have a riprap layer thickness of 13.5 inches, the distance extended horizontally from the toe is:

$$5 \times 13.5" = 67.5" (\text{say } \underline{6 \text{ ft.}})$$

For the Moab Wash riprap corresponding to section P-P', which has a riprap layer thickness of 8" (see Table 2), the distance extended horizontal from the toe is:

$$5 \times 8" = 40" (\underline{\text{say } 3.5'})$$

C. Filter Requirements

The same filter rock gradations as developed in the Atlas Corp. Reclamation Plan (Canonie, June 1992) will be placed under the Moab Wash riprap. Both Filter I and Filter II are required beneath the Moab Wash riprap (SECTIONS L-L, M-M; N-N') to prevent fine grained soils from migrating into the 9" D_{50} riprap layer as shown by the following calculations:

- From upper limit curve on Figure 5, D_{15} riprap = 6.4"
- Minimum D_{85} Filter with respect to riprap = D_{15} riprap/5 (NUREG 4620) or D_{85} filter = 6.4/5 = 1.28 "
- From Atlas Corp. Rec. Plan (Canonie, 1992 Appendix E) , Minimum D_{85} Filter with respect to soil base = 0.92" which is less than 1.28" therefore, a second filter is required.

For the smaller riprap size of section P-P' (See Figure 1 for location) which corresponds the 4.1" D_{50} riprap gradtion developed in the Atlas Corp. Rec. Plan (Canonie, 1992), only Filter I is required. Refer to Rock Quality - Assessment of Oversizing Requirements Atlas Corp. Reclamation Plan (Canonie, June 1992), Appendix E for detailed discussion of filter design requirements.

2. Northeast Debris Pit Riprap. The riprap required to protect the Northeast Debris Pit from runoff from the 10:3 embankment is designed considering overland flow erosion. Riprap protection for overland flow erosion is designed using the Stephensen's method for slopes greater than 10 percent and the safety factors method for slopes less than 10 percent. These methods are outlined in the NRC NUREG-4620 and NUREG-4651 and in Appendix C of the Atlas Corp. Reclamation Plan (Canonie, June 1992).

Peak discharge on the 10:3 embankment and on the 1% slope over the debris pit (refer to Figure 4 for a profile of the 10:3 and 1% slopes and Northeast Debris Pit) are added together to determine the D_{50} size. In Appendix C of the Atlas Corp.

Reclamation Plan (Canonie, June 1992), riprap protection was designed for the 10:3 embankment areas. Table 3 (sheet 17) (taken from Appendix C of the Atlas Corp. Reclamation Plan (Canonie, June 1992)) shows the results from for the 10:3 embankment area immediately adjacent to the debris pit as computed using Stephensen's method. The peak discharge on the 10:3 slope assuming a unit width is 0.374 cfs. Table 4 (sheet 18) shows the overland flow calculations using the Safety Factors method for the 1% slope. The peak discharge on the 1% alone is 0.188 cfs. The total discharge on the 1% slope is therefore, 0.374 + 0.188 = 0.562 cfs. Using this combined discharge, the required D_{50} on the 1% slope over the debris pit is computed. The results using the Safety Factors method are displayed on Table 5 (sheet 19). A D_{50} of 0.4 inches on the 1% slope is required. This is a raw D_{50} and must be oversized 15% for durability and 20% for roundness. The necessary D_{50} is:

0.4" x 1.15 x 1.20 = 0.55 "

The 1" Rock Mulch Gradation (1.3" D_{50}) developed in the Atlas Corp. Rec. Plan (Canonie, June 1992) will be used for the erosion protection over the northeast debris pit area. This riprap gradation is repeated in Table 2 as the riprap required to protect the Northeast debris pit from runoff from the 10:3 embankment.

To prevent the developing of scour holes along the toe of the 10:3 embankment and possible undercutting of the riprap over the Northeast Debris pit, the 4.1" D_{50} riprap is extended 3 ft. out from the toe. Based on the toe protection methods presented in "Erosion Protection of Uranium Tailings Impoundments" (NRC, 1986) (See Attachment A for excerpts), riprap should be extended at a minimum of 1.5 x the depth of scour. From Appendix D of the Atlas Corp. Response to NRC Comments (Canonie, April 1993) report, the worst case depth of scour at the toe of the 10:3 embankment was determined as 0.92 ft. Therefore, extending the 4.1" D_{50} riprap protection 3 feet is conservative (1.5 x 0.92' = 1.4' < 3').

3. Scour Depth. To determine scour depth resulting from Moab Wash flows, the applicable methods listed in Pemberton (1984) (see Attachment C for excerpts) will be used. Specifically, equations for riprap bank slope protection will be applied. Velocities from the HEC-2 supercritical run (see Attachment B) are greater than the subcritical velocities and will be used to compute the depth of scour. The depth of scour methods are summarized below:

Method 1. Field Measurement of Scour.

$d_s = K\,(q)^{0.24}$ (eq. 24 in Attachment C)

$K = 2.45$ (constant)

q = discharge (ft^3/s) / topwidth of channel flow (ft). Total PMF discharge in Moab Wash Channel (see Attachment B) is 16,129 cfs. Topwidth of channel flow for the sections along Moab Wash are given as part of the HEC-2 output in Attachment B.

Method 2. Regime Equation by field measurement

a. Lacey Empirical Equation:

$d_m = 0.47\,(Q/f)^{1/3}$ (eq. 26 in Attachment C)

Q = design discharge, cfs

f = Lacey silt factor = $1.76\,D_m^{\ 1/2}$ where D_m = mean grain size of bed material = 0.16 mm as shown on Figure 6.

$d_s = Z\,d_m$ where $Z = .25$ straight bends, 0.5 moderate bends, and 0.75 for severe bends (see table 7 in Attachment C)

b. Blench Equation for zero bed factor.

$d_{fo} = (q_f)^{2/3}/F_{bo}^{\ 1/3}$ (eq. 27 in Attachment C)

d_{fo} = depth for zero bed sediment transport, ft

q_f = design flood discharge per unit width (same as q in method 1)

F_{bo} = Blench's zero bed factor in ft/s^2. From Attachment C (sheet 53) using $D_m = 0.16$ mm, $F_{bo} = 0.8\ ft/s^2$

$d_s = z\,d_{10}$ where $z = 0.6$ for straight, moderate, and severe bends.

Method 3. Mean Velocity Method from field measurements:

$d_s = d_m Z$

d_m = mean channel depth (ft) = area of flow (ft^2)/topwidth of flow (ft)

z = defined above as for method 2a.

Method 4. Competent or limiting control to scour method:

$d_s = d_m (V_m/V_c - 1)$ (eq. 32 Attachment C)

where

d_s = scour depth, ft

d_m = mean depth, ft = area/topwidth

V_m = mean velocity, ft/s = Q/A

V_c = competent velocity, ft/s ≈ 2 ft/s (SHEET 53, Attachment. C using lowest bed material size on figure and depth of flow of 5 ft.)

Calculations for sections L-L', M-M', N-N' and P-P' are summarized in Table 6. The final scour depth is computed by averaging scour depths from each of the methods. From the literature supplied in Attachment C, method 1 and 4 presented above may not be entirely applicable because these methods are more applicable with coarser bed size material. However, by using these methods, the final averaged scour depth result is slightly more conservative.

From the depth of scour the width of riprap along the Moab Channel bank is determined as using the equations for width shown in Figure 3 and 4. Flow, area, channel topwidth, and depth of flow values in Table 6 are from the Moab Wash HEC-2 supercritical run found in Attachment B and appendix G of the Atlas Corp. Rec. Plan (Canonie, June 1992).

4. Volume of Riprap. The volume of required riprap is computed from the width of riprap, length of riprap along the channel bank, and layer thickness. Table 7b (sheet 22) provides a summary of the riprap length, riprap mean grain size, riprap layer thickness, required volume of riprap, and required volume of filter material for the Moab Wash Channel bank protection and for the Northeast Debris pit riprap protection. Table 7a summarizes the scour depth, invert elevation of riprap and top of riprap elevation for the Moab Wash Channel Bank protection.

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TABLES

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Table 1.

Summary of Corps of Engineers Method for Riprap Sizing
Moab Wash Realignment

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Section	Depth of Flow(1) ft	Main Channel Velocity (1), ft/s	Riprap Minimum Mean Grain Size(2) (D50) ft	in	Local Shear(2) psf	Allowable Bottom Shear (2) psf	Allowable Side Shear (2) psf
L-L'	3.99	11.72	0.73	8.8	2.42	2.68	2.42
M-M'	4.70	10.52	0.45	5.4	1.47	1.65	1.49
N-N'	4.61	11.08	0.55	6.6	1.78	2.02	1.82
P-P'	2.31	6.83	0.20	2.4	0.59	0.73	0.66

Notes:
(1) From HEC-2 Moab Wash Supercritical Run.(see Attachment B)
(2) Calculated using Corp of Engineers Method.

8/27/93 SUMM.XLS

TABLE 2

SUMMARY OF RIPRAP GRADATION REQUIREMENTS
(Allowable Percent Passing Given Dimension)

Location	Necessary D50 (a) (inches)	Actual D50 (inches)	Riprap Layer Thickness (inches)	54"	48"	36"	24"	20"	15"	12"	10"	6"	4"	3"	2"	1"	3/4"	1/2"	3/8"	Sieve No. 4	Rock Type (b)
Lower Southwest Drainage Channel	32.4	32.4	49		100	42-60	16-34	10-26	4-16	0-12											CD
Lower Impoundment Drainage Channel	17.1	17.1	26				100	54-70	30-40	16-31	8-25	0-12									CD
Moab Wash Channel Bank (sec. L-L' to N-N')	9.0	9.0	13.5							100	38-64	12-30	0-18	0-10							CD
Upper Southwest Drainage Channel	4.9	4.9	10								100	46-60	20-40	8-28	0-14						CD
Upper Impoundment Drainage Channel	4.3																				CD
Collection Ditches	3.3	4.1	8									100	34-48	18-32	2-19	0-3					CD
10:3 Embankment	4.1																				
10:1 Embankment	2.7																				
Moab Wash (Sec P-P')	3.3																				
Northeast Debris Pit	0.55	1.3	3										100	82-100	50-78	18-35	8-23	0-12			RA

(a) Necessary riprap D50 based on design requirements and includes oversizing for rock durability and roundness (as necessary). See Appendix E.
(b) Gradation requirements are based on rock durability ratings for particular material: "CD" denotes crushed diorite rock type.
(c) Gradation requirements are based on rock durability ratings for particular material: "RA" denotes round alluvial cobbles.

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TABLE 3

OVERLAND FLOW CALCULATIONS AND RIPRAP SIZING USING THE STEPHENSON'S METHOD
FOR SLOPES 10% OR GREATER

OVERSTEP.WR1
20-May-92
07:27 PM

CKD: JDG 5/21/92

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PROJECT: Atlas 88-067-08
LOCATION: A7 - 10:3 SLOPE ADJACENT DEBRIS PIT
(TAKEN FROM APP. C - JUNE 92 REC. PLAN PAGE C-22)

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments, Sections 2.1.2 and 4.8)

INPUT PARAMETERS

SIDESLOPE LENGTH: 300 FT
SIDESLOPE: 0.3 FT/FT
RETURN PERIOD: PMP
1-HR PPT AMOUNT: 8.25 INCHES
RUNOFF COEFF (C): 1.00 Intro.Hydr
FLOW CONC: 1.00 NRC Rec. Value

CALCULATED PARAMETERS

DRAINAGE AREA (Aw): 0.006 ACRES
Tc (calc): 1.002 MIN REF.: NRC NUREG 4620. Eqn 4.45
RATIO TO 1-HR PPT: 0.11 TABLE 2.1 NRC NUREG 4620
RAINFALL DEPTH: 0.91 INCHES
INTENSITY (i): 54.44 INCHES/HOUR

PEAK DISCHARGE (q): 0.374 CFS/FT q = C*i*Aw FOR UNIT WIDTH ANAL.

TABLE 2.1 NRC NUREG 4620

RAINFALL DURATION (MIN)	PERCENT 1 HOUR PMP	INTERPOLATED VALUE FOR Tc
0	0	11.0
2.5	27.5	
5	45	
10	62	
15	74	
20	82	
30	89	
45	95	
60	100	

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RIPRAP SIZING CALCULATIONS (NUREG-4620, Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments, Section 4.2.2.2)

INPUT PARAMETERS:

Acceleration of Gravity (g): 32.2 FT/SEC^2 Constant
Riprap Friction Angle (phi): 42.00 degrees
Riprap Relative Density (s): 2.47 MEASURED
} Crushed Igneous Rock
Riprap Porosity (n): 0.45 ASSUMED American Water Resources Association
Empirical Constant (c): 0.27 ASSUMED (Ranges from 0.22 for gravel and pebbles to 0.27 for crushed granite)

CALCULATIONS:

Maximum Flow Rate (q): 0.375 CFS/FT From Above Calc.
Slope Angle (theta): 16.70 degrees Based on Sideslope

Riprap d50: 0.328 Feet NUREG 4620, Equation 4.28
Or d50= 3.944 Inches

SFRR_DP.XLS 7/23/93

TABLE 4

√ JG 8/27/..

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: Atlas 88-067-10
LOCATION: North East Debris Pit(only flow from 1% slope,10:3 embnk. not includec

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OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments

INPUT PARAMETERS			CALCULATED PARAMETERS		
RUNOFF COEF:	1		DRAINAGE AREA:	0.003	ACRES
SLOPE LENGTH:	150	FT			
AVE SLOPE:	0.01	FT/FT	Tc (actual):	2.18	MIN EQ 4.44, NUREG 4620
RETURN PERIOD:	PMP	YRS	%OF 1-HR PPT:	23.94	% TABLE 2.1, NUREG 4620
1-HR PPT AMOUNT:	8.25	INCHES	PPT AMOUNT:	1.975	INCHES
FLOW CONC:	1		PPT INTENSITY:	54.46	INCHES/HOUR
Mannings n(assumed):	0.020	***	nnings n(calc):	0.020	ANDERSONS METHOD USED IF SLOPE CSU METHOD USED IF SLOPE>2%
			PEAK DISCHARGE:	0.188	CFS Q = CiA
			CONC. DISCHARGE:	0.188	CFS CONC. FACTOR = 1
			DEPTH:	0.11	FT EQTN 4.46, NUREG 4620
			TRACTIVE FORCE:	0.069	PSF 62.4 * depth * slope
			FLOW VELOCITY:	1.71	FPS V = Q/FLOW AREA

TABLE 2.1 - NUREG 4620
Percent of 1-hr local-storm PMP for selected durations for 6-hr /1-hr ratio of 1.2 (HMR No.

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT	INTERPOLATED PERCENT
0	0	23.94
2.5	27.5	
5	45	
10	62	
15	74	
30	89	
45	95	
60	100	

Note: Interpolated percent bas on Tc(actual)

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap Design Criteria by Riprap Testing in Flumes:Phase I, Safety Factor Method)

INPUT PARAMETERS:			CALCULATIONS:		
Spec. weight of water	62.40	pcf	TAN(phi):	0.754	
Rock Specific Gravity	2.45		cos(alpha):	1	
Angle of Friction(phi	37.00	degrees	sin(alpha):	0.01	
Channel Slope (alpha)	0.57	degrees	x:	0.016	
Safety factor:	1		y:	0.744	
			D50:	0.016	feet
				0.19	inches

TABLE 5.

JAL 8/27/93

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: Atlas 88-067-10
LOCATION: North East Debris Pit (flow from 10:3 and 1% included)

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments

INPUT PARAMETERS		
RUNOFF COEF:	1	
SLOPE LENGTH:	150	FT
AVE SLOPE:	0.01	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	8.25	INCHES
FLOW CONC:	1	
Mannings n(assumed):	0.022	***

CALCULATED PARAMETERS		
DRAINAGE AREA:	0.003	ACRES
Tc (actual):	2.18	MIN EQ 4.44, NUREG 4620
%OF 1-HR PPT:	23.94	% TABLE 2.1, NUREG 4620
PPT AMOUNT:	1.975	INCHES
PPT INTENSITY:	54.46	INCHES/HOUR
nnings n(calc):	0.022	ANDERSONS METHOD USED IF SLOPE CSU METHOD USED IF SLOPE>2%
PEAK DISCHARGE:	0.562	CFS Q = CiA
CONC. DISCHARGE:	0.562	CFS CONC. FACTOR = 1
DEPTH:	0.225	FT EQTN 4.46, NUREG 4620
TRACTIVE FORCE:	0.14	PSF 62.4 * depth * slope
FLOW VELOCITY:	2.50	FPS V = Q/FLOW AREA

TABLE 2.1 - NUREG 4620
Percent of 1-hr local-storm PMP for selected durations for 6-hr /1-hr ratio of 1.2 (HMR No.

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT	INTERPOLATED PERCENT
0	0	23.94
2.5	27.5	
5	45	
10	62	
15	74	
30	89	
45	95	
60	100	

Note: Interpolated percent bas
on Tc(actual)

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap Design Criteria by Riprap Testing in Flumes:Phase I, Safety Factor Method)

INPUT PARAMETERS:		
Spec. weight of water	62.40	pcf
Rock Specific Gravity	2.45	
Angle of Friction(phi	37.00	degrees
Channel Slope (alpha)	0.57	degrees
Safety factor:	1	

CALCULATIONS:		
TAN(phi):	0.754	
cos(alpha):	1	
sin(alpha):	0.01	
x:	0.033	
y:	0.744	
D50:	0.033	feet
	0.40	inches

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✓ JAK 8/27/93

Table 6

Summary of Scour Depth Calculations

Method 1

Section	Q, ft³/s (3)	Top Width, ft. (3)	q, ft	ds, ft
L-L'	16129	500.54	32.22	**5.64**
M-M'	16129	465.47	34.65	**5.74**
N-N'	16129	452.34	35.66	**5.78**
P-P'	16129	1686.56	9.56	**4.21**

Method 2a

Section	Bend Type (4)	Z (5)	Dm, mm	f	dm,ft	ds,ft
L-L'	Moderate	0.5	0.16	0.70	13.35	**6.67**
M-M'	Moderate	0.5	0.16	0.70	13.35	**6.67**
N-N'	Severe	0.75	0.16	0.70	13.35	**10.01**
P-P'	Moderate	0.5	0.16	0.70	13.35	**6.67**

Method 2b

Section	Fbo, ft/s²	dfo, ft	Z (5)	ds, ft
L-L'	0.8	10.91	0.6	**6.54**
M-M'	0.8	11.45	0.6	**6.87**
N-N'	0.8	11.67	0.6	**7.00**
P-P'	0.8	4.85	0.6	**2.91**

Method 3

Section	Bend Type	Area (3) ft²	Top Width(3) ft	dm, ft	z (5)	ds, ft
L-L'	Moderate	1385.19	500.54	2.77	0.50	**1.38**
M-M'	Moderate	1544.99	465.47	3.32	0.50	**1.66**
N-N'	Severe	1466.19	452.34	3.24	0.75	**2.43**
P-P'	Moderate	2361.89	1686.56	1.40	0.50	**0.70**

Method 4

Section	Q, ft³/s	Area (3) ft²	Vm, ft/s	Vc, ft/s	dm,ft	ds, ft
L-L'	16129	1385.19	11.64	2	2.77	**13.34**
M-M'	16129	1544.99	10.44	2	3.32	**14.01**
N-N'	16129	1466.19	11.00	2	3.24	**14.59**
P-P'	16129	2361.89	6.83	2	1.40	**3.38**

Summary of Methods - Scour Depths, ft

Section	Method 1	Method 2a	Method 2b	Method 3	Method 4	Average Scour Depth, ft
L-L'	5.64	6.67	6.54	1.38	13.34	**6.72**
M-M'	5.74	6.67	6.87	1.66	14.01	**6.99**
N-N'	5.78	10.01	7.00	2.43	14.59	**7.96**
P-P'	4.21	6.67	2.91	0.70	3.38	**3.58**

Table 6

Summary of Scour Depth Calculations

✓ 21/68
Jel 8/27/93

Notes:

1) Scour Depth based on Moab Wash HEC-2 Supercritical run where velocites are greatest.
2) See main text for description of methods and equations.
3) From HEC-2 Supercritical Run (See Attachment B)
4) Bend types conservatively assumed.
5) From Table 7 in Attachment C.

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✓ REVISED TABLE
(ADD FILTER I TO II
[illegible])
9/20/93

Table 7a.

Summary of Moab Wash Channel Bank Riprap Invert and Top Elevations.

Moab Wash Channel Section	Invert Elevation of Inner Channel(1), ft. msl.	Scour Depth(2) ft	PMF Water Surface Elev.(1) ft	Riprap Invert Elevation(3) ft. msl.	Top of Riprap Elevation(4) ft. msl.
L-L'	3987.3	6.72	3992.4	3980.6	3993.4
M-M'	3981.5	6.99	3986.5	3974.5	3987.5
N-N'	3974.1	7.96	3979.4	3966.1	3980.4
P-P'	3965.3	3.58	3969.7	3961.7	3970.7

Notes:

1) See Figure 2 for Invert and PMF Surface Water Elevations. (Subcritical depth used, and is conservative)
2) Scour Depth computed based on supercritical velocites, see Table 6.
3) Equivalent to Depth of Scour. (inner channel minus scour depth)
4) PMF Water Elev. + 1' Free Board.

Table 7b.

Summary of Moab Wash Channel Bank and Northeast Debris Pit Erosion Protection Design

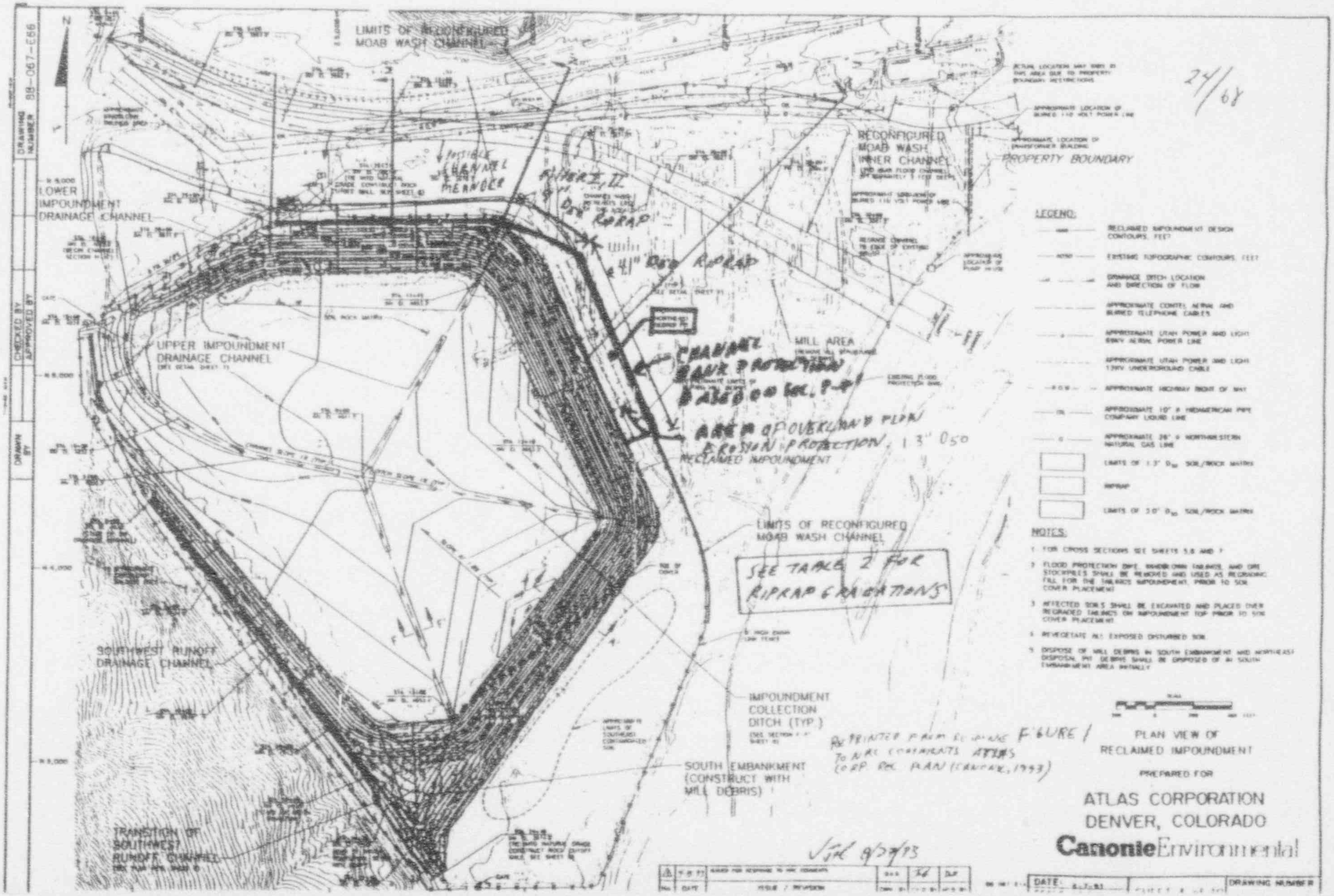
Type of Ersoion Protection	Location of Erosion Protection	Riprap Width(2) ft.	Riprap Length (3) ft.	Mean Grain Size Diameter of D50, in (4)	Riprap Thickness(5) in	Required Riprap Volume. CY	Required Filter I Material Volume(6) CY	Required Filter II Material Volume(6) CY
Channel Bank	From L-L' to M-M'	50.6	600	9	13.50	1265.4	582.4	562.4
Channel Bank	From M-M' to N-N'	51.2	570	9	13.50	1216.2	540.6	540.6
Channel Bank	300 ft. past N-N'	55.6	300	9	13.50	695.3	309.0	309.0
Channel Bank	To end of Debris Pit	31.9	1000	4.1	6.00	590.7	590.7	NR
Overland Flow	Over Northeast Debris Pit	150	1000	1.3	6	2777.8	NR	NR

Notes:

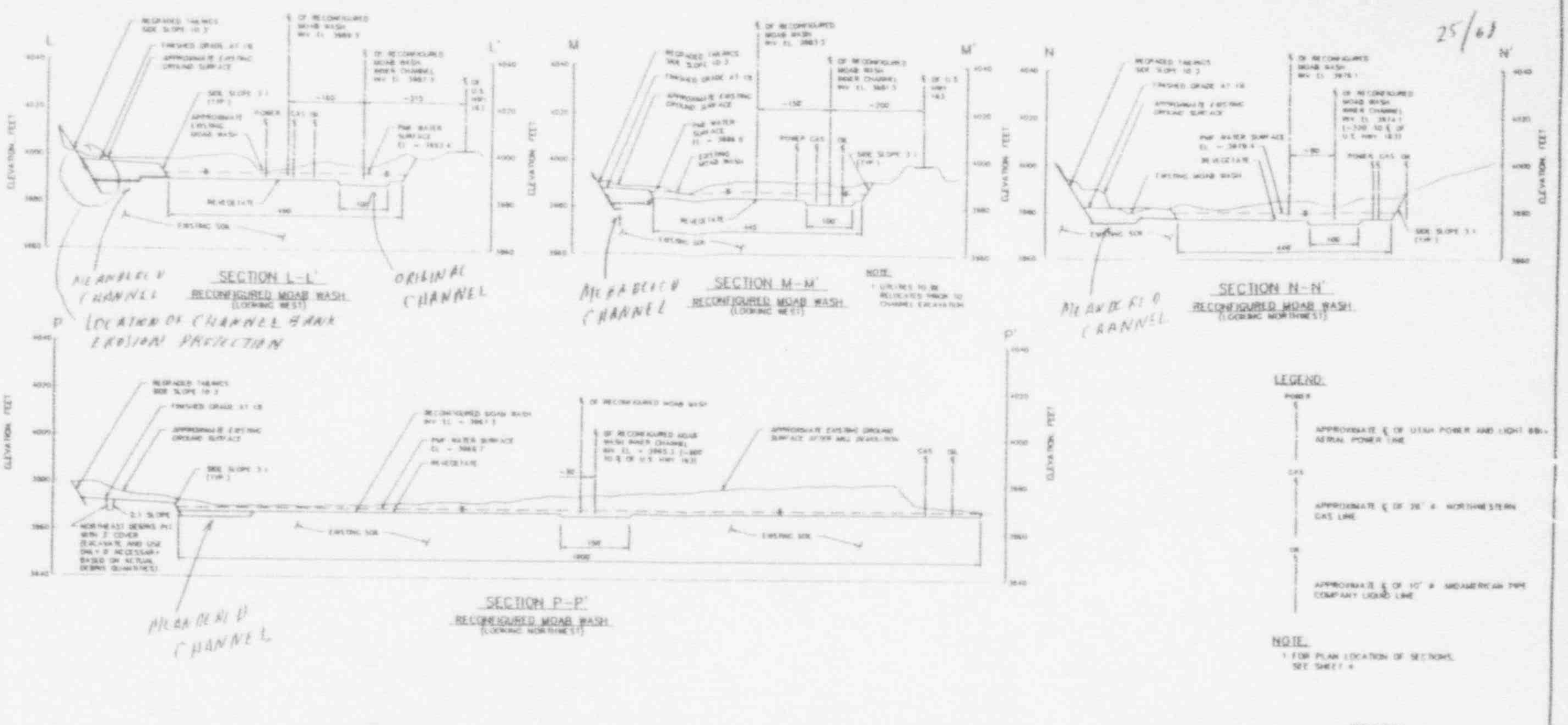
1) See Table 6 for Scour Depth Calculations
2) Riprap width includes 6 ft. along impoundment toe and 3.5 ft at Northeast debris pit.
3) Riprap Length Determined from Figure 1.
4) See Table 2 for Gradation Requirements for Riprap.
5) Riprap Layer Thickness = 1.5 x D50 when D50 > 8" and = 2 x D50 when 3" < D50 < 8" and minimum of 6" when D50 < 3" (NRC, Final STP, 1990).
6) When required, Filter Material Volume Calculation based on 6" filter layers.
7) NR denotes not required.

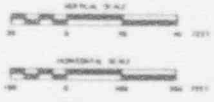
SUMRY XLS 9/17/93

FIGURES

24/68
N
DRAWING NUMBER 88-067-E66
CHECKED BY
APPROVED BY
DRAWN BY
LIMITS OF RECONFIGURED MOAB WASH CHANNEL
LOWER IMPOUNDMENT DRAINAGE CHANNEL
UPPER IMPOUNDMENT DRAINAGE CHANNEL
SOUTHWEST RUNOFF DRAINAGE CHANNEL
TRANSITION OF SOUTHWEST RUNOFF CHANNEL
POSSIBLE CHANNEL MEANDER
RIVER I, II
D50 RIPRAP
41" D50 RIPRAP
RECONFIGURED MOAB WASH INNER CHANNEL
PROPERTY BOUNDARY
MILL AREA
CHANNEL BANK PROTECTION BASED ON SEC. F-F
AREA OF OVERLAND FLOW EROSION PROTECTION, 13" D50
RECLAIMED IMPOUNDMENT
LIMITS OF RECONFIGURED MOAB WASH CHANNEL
SEE TABLE 2 FOR RIPRAP GRADATIONS
IMPOUNDMENT COLLECTION DITCH (TYP.)
SOUTH EMBANKMENT (CONSTRUCT WITH MILL DEBRIS)
LEGEND:
RECLAIMED IMPOUNDMENT DESIGN CONTOURS, FEET
EXISTING TOPOGRAPHIC CONTOURS, FEET
DRAINAGE DITCH LOCATION AND DIRECTION OF FLOW
APPROXIMATE CONTEL AERIAL AND BURIED TELEPHONE CABLES
APPROXIMATE UTAH POWER AND LIGHT 69KV AERIAL POWER LINE
APPROXIMATE UTAH POWER AND LIGHT 13KV UNDERGROUND CABLE
APPROXIMATE HIGHWAY RIGHT OF WAY
APPROXIMATE 10" Ø MIDAMERICAN PIPE COMPANY LIQUID LINE
APPROXIMATE 26" Ø NORTHWESTERN NATURAL GAS LINE
LIMITS OF 1.3" D50 SOIL/ROCK MATRIX
RIPRAP
LIMITS OF 3.0" D50 SOIL/ROCK MATRIX
NOTES:
1. FOR CROSS SECTIONS SEE SHEETS 5,6 AND 7
2. FLOOD PROTECTION DIKE, WINDBLOWN TAILINGS, AND ORE STOCKPILES SHALL BE REMOVED AND USED AS REGRADING FILL FOR THE TAILINGS IMPOUNDMENT, PRIOR TO SOIL COVER PLACEMENT
3. AFFECTED SOILS SHALL BE EXCAVATED AND PLACED OVER REGRADED TAILINGS ON IMPOUNDMENT TOP PRIOR TO SOIL COVER PLACEMENT
4. REVEGETATE ALL EXPOSED DISTURBED SOIL
5. DISPOSE OF MILL DEBRIS IN SOUTH EMBANKMENT AND NORTHEAST DISPOSAL PIT. DEBRIS SHALL BE DISPOSED OF IN SOUTH EMBANKMENT AREA INITIALLY
SCALE
PLAN VIEW OF RECLAIMED IMPOUNDMENT
PREPARED FOR
ATLAS CORPORATION
DENVER, COLORADO
Canonie Environmental
Re-printed from response Figure 1 to NRC comments Atlas (orp Rec Plan (Canonie, 1993)
JJK 9/27/93
ISSUE / REVISION
DATE
DRAWING NUMBER

25/63





DEPTH OF SCOUR AND 'WIDTH' OF SCOUR PROTECTION ALLOWS [illegible] CHANNEL MEANDERS AGAINST SOUTH BANK, AS SHOWN.

FIGURE 2

REPRINTED FROM RESPONSE TO NRC COMMENTS ATLAS CORP REC. PLAN (CANONIE, 1993)

RECONFIGURED MOAB WASH

CHANNEL CROSS SECTIONS

PREPARED FOR

ATLAS CORPORATION
DENVER, COLORADO

Canonie Environmental

4	[illegible] 93	ISSUED FOR RESPONSE TO NRC COMMENTS	[illegible]	[illegible]	[illegible]
3	[illegible]	ISSUED FOR REVISED RECLAMATION PLAN	[illegible]	[illegible]	[illegible]
2	[illegible]	REVISED FOR USE AS CONSTRUCTION DRAWINGS	[illegible]	[illegible]	[illegible]
1	8-4-88	ISSUED AS ENGINEER'S REPORT RECLAMATION PLAN URANIUM MILL AND TAILINGS DISPOSAL AREA	R.H. 7-26-88	P.E.C. 8-4-88	O.P.W. 8-4-88
NO.	DATE	ISSUE NUMBER / REVISIONS	DWN BY DATE	CHK'D BY DATE	APP'D BY DATE

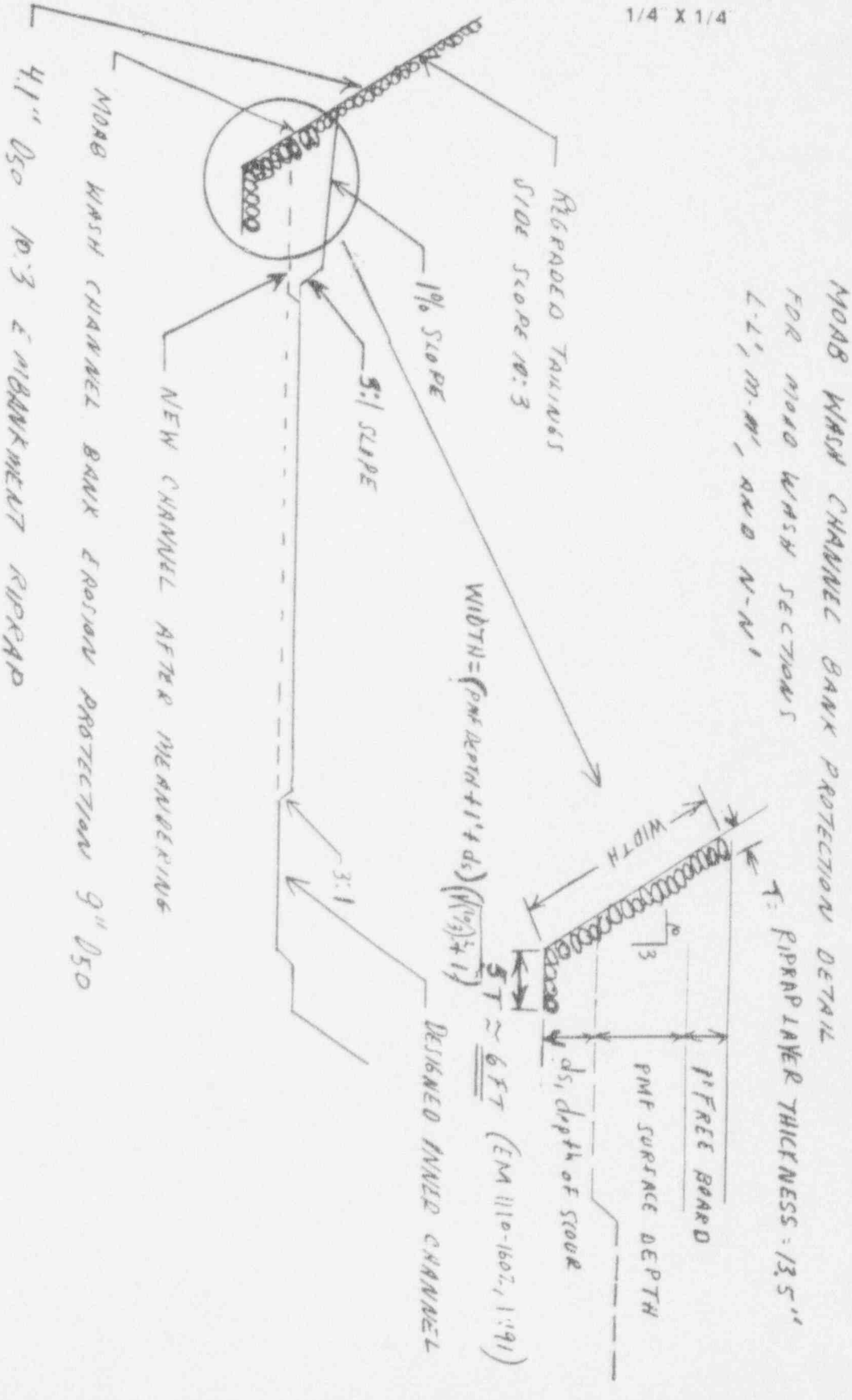
DATE	7-23-88	SHEET 7 of 10	DRAWING NUMBER	REV
SCALE	AS SHOWN		88-067-E16	4

DRAWN BY	R.H. 7-23-88	CHECKED BY APPROVED BY	P.E.C. 8-4-88 O.P.W. 8-4-88	DRAWING NUMBER 88-067-E16

By JWS Date 8/26/93 Subject MOABWASH/NORTHEAST Sheet No. 26 of 68
Chkd. By Date 8/27/93 DEBRIS PIT EROSION PROTECTION Proj. No 88-067-10

1/4" X 1/4"

FIGURE 5.
MOAB WASH CHANNEL BANK PROTECTION DETAIL
FOR MOAB WASH SECTIONS
L-L', M-M', AND N-N'



CanonieEnvironmental

By JWS Date 8/26/93 Subject MOAB WASH/NORTHEAST DEBRIS PIT EROSION PROTECTION Sheet No. 27 of 68
Chkd. By [illegible] Date 8/27/93 Proj. No 88-067-10
1/4" X 1/4"

FIGURE 4

NORTHEAST DEBRIS PIT
EROSION PROTECTION DETAIL (FOR MOAB WASH SECTION R-R')

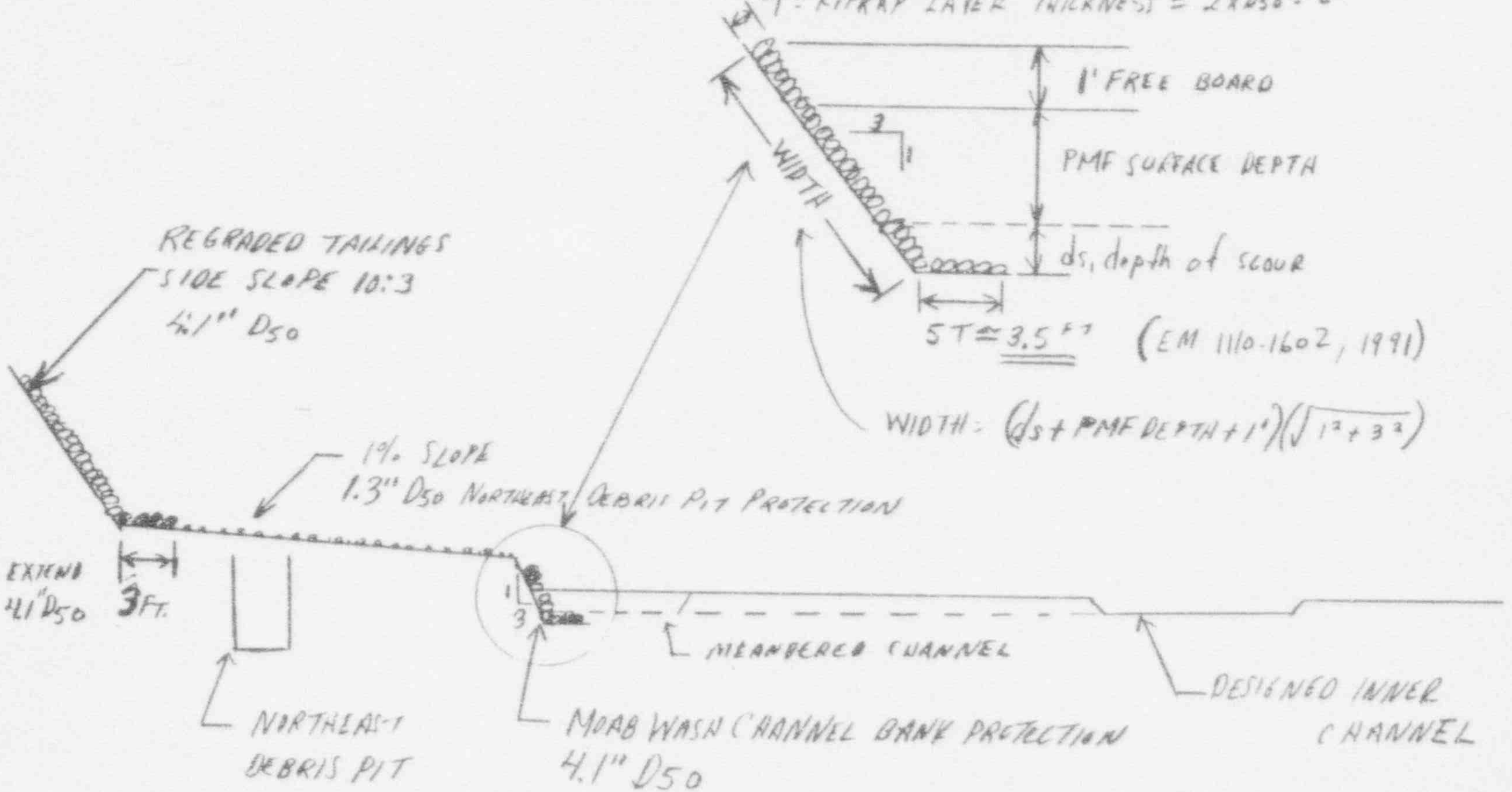


FIGURE 5. RIPRAP GRADATION ENVELOPE FOR MOAB WASH CHANNEL BANK PROTECTION.

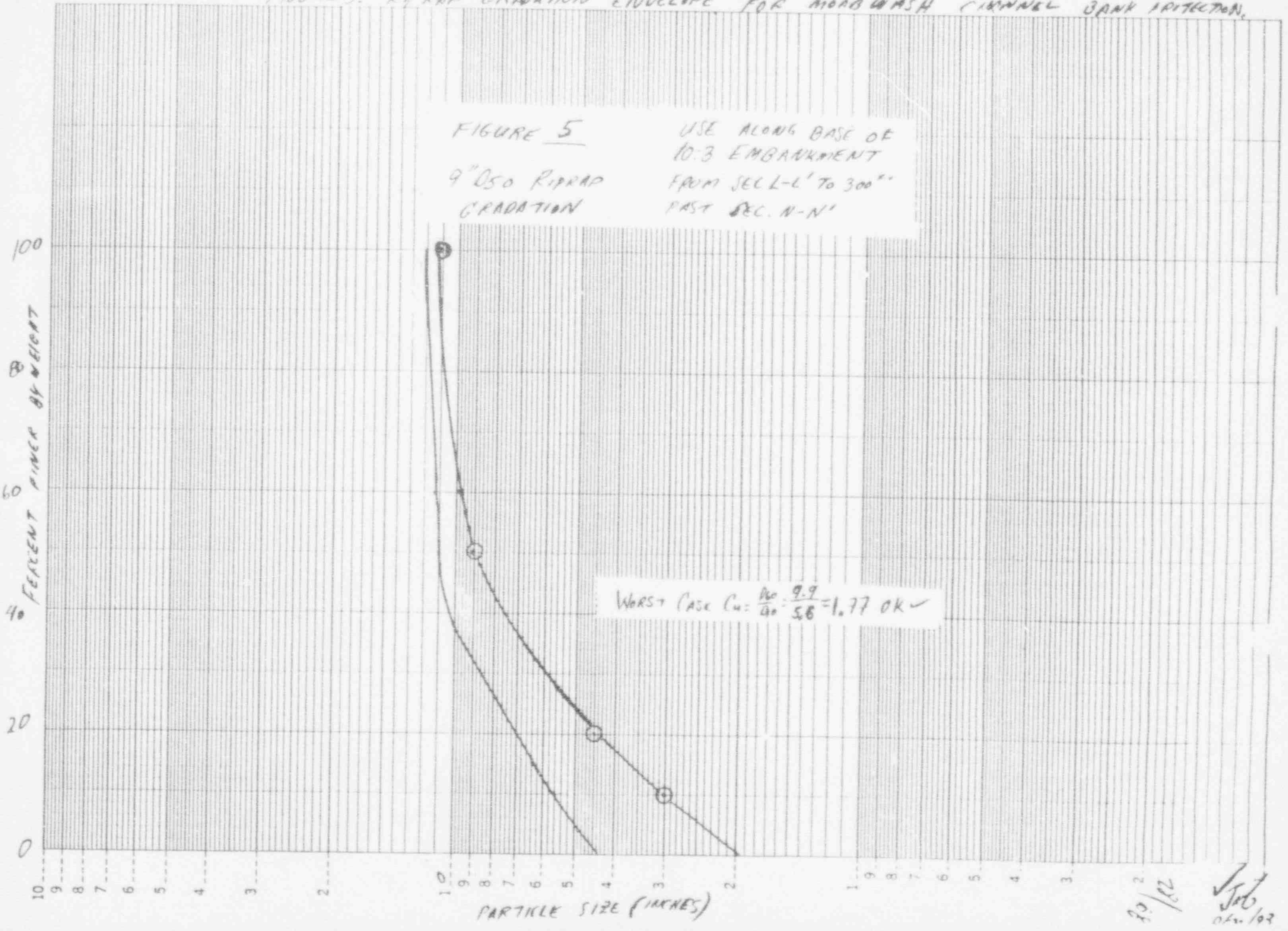


FIGURE 5

9" D50 RIPRAP GRADATION

USE ALONG BASE OF 10:3 EMBANKMENT FROM SEC L-L' TO 300 ± PAST SEC. N-N'

WORST CASE $C_u = \frac{D_{60}}{D_{10}} = \frac{9.9}{5.6} = 1.77$ OK ✓

23/12

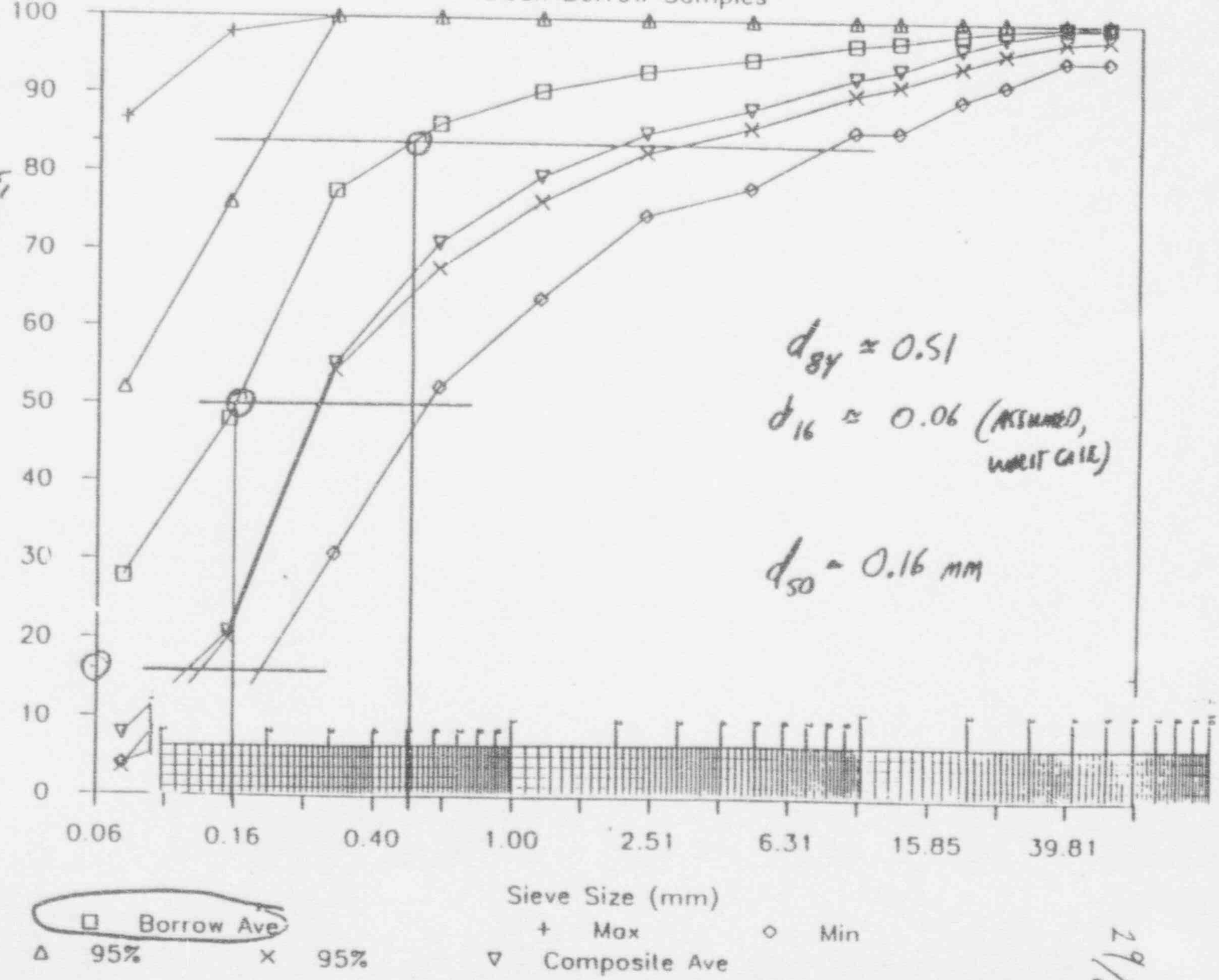
✓ JRT
Oct. /92

Figure 6

Grain Size Distribution for
Clean Borrow Samples

REPRINTED FROM
ATLAS CORP.
REG PLAN [illegible],
1992 APPENDIX B

8/30/93



$d_{84} \approx 0.51$

$d_{16} \approx 0.06$ (ASSUMED, WORST CASE)

$d_{50} = 0.16$ mm

ATTACHMENT A - EXCERPTS FROM EM 1110-2-1601 AND NUREG/CR-4480

REPRINT WITH CHANGE 1 thru 4 INCLUDED.

ENGINEER MANUAL

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EM 1110-2-16

1 JULY 197

ENGINEERING AND DESIGN

HYDRAULIC DESIGN OF FLOOD CONTROL CHANNELS

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

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the interaction of the local boundary shear and the size and gradation of the riprap material.

(2) Average boundary shear. The average boundary shear over the wetted perimeter of a channel cross section (from ref 3) is given by

$$\bar{\tau}_o = \gamma RS \tag{30}$$

where

$\bar{\tau}_o$ = average boundary shear, psf
γ = unit weight of water, pcf
R = hydraulic radius, ft
S = slope of energy gradient

By utilizing equations 1 and 6, equation 30 becomes

$$\bar{\tau}_o = \frac{\gamma V^2}{\left(32.6 \log_{10} \frac{12.2R}{k}\right)^2} \tag{31}$$

where

V = average cross-sectional velocity, fps
k = equivalent channel boundary surface roughness, ft

(3) Local boundary shear. In a straight trapezoidal channel with equal bottom and side roughness, the boundary shear varies over the wetted perimeter as shown in plate 31. By substituting in equation 31 the depth Y (in feet) for R, the average local velocity in the vertical $\bar{v}$ (in feet per second) for V, and the average stone theoretical diameter D_{50} (in feet) for k, the local boundary shear at any point on the wetted perimeter can be determined by the equation

$$\tau_o = \frac{\gamma \bar{v}^2}{\left(32.6 \log_{10} \frac{12.2y}{D_{50}}\right)^2} \tag{32}$$

The average local velocity in the vertical at any point should be determined as illustrated in Appendix IV. The subsection width used to determine $\bar{v}$ should not be too great. Where there is a significant difference in roughness over the wetted perimeter, as may occur in a channel with riprap bank revetment and a natural invert, a local effective friction coefficient as determined from Hydraulic Design Chart 631-4 or Appendix IV should be used in computing values of $\bar{v}$. A graphic solution of equation 32 is presented in plate 32.

(4) Boundary shear in bends. The distribution of local boundary shear in a bend of a trapezoidal channel with equal bottom and side roughness is indicated in plates 33 and 34 (compiled from data in refs 53, 54, and 55). * Average boundary shear values obtained by equation 31 should be multiplied * by the indicated ratios of $\tau_b/\bar{\tau}_o$ to obtain local boundary shear values in a bend.

(5) Riprap design shear. The riprap design shear is defined as that amount of local boundary shear that the in-place riprap will safely withstand. The design shear for riprap placed on an essentially level channel bottom is given by reference 56.

$$\tau = a\ (\gamma_s - \gamma)D_{50} \tag{33}$$

where

γ_s = the unit weight of stone saturated surface dry (SSD)

coefficient "a" = 0.040

The design shear for riprap placed on channel side slopes is given by the following equation taken from reference 3

$$\tau' = \tau\left(1 - \frac{\sin^2\phi}{\sin^2\theta}\right)^{0.5} \tag{34}$$

where

ϕ = the angle of the side slope with the horizontal

θ = the angle of repose of the riprap, normally about 40 deg

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EM 1110-2-16
1 July 19

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ENGINEERING AND DESIGN

Hydraulic Design of Flood Control Channels

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(2) Trench-fill revetments: riprap placed at low water level

(3) Weighted riprap toes: riprap placed at intersection of channel bottom and side slope

Trench-fill revetments on the Mississippi River have successfully launched to protect for a vertical scour depth of up to 50 ft. On gravel bed streams, the use of launchable stone is not as widely accepted as in sand bed streams. Problems with using launchable stone in some gravel bed rivers may be the result of underestimating stone size, scour depth, or launchable stone volume because the concept of launchable stone has been successful on several gravel bed rivers.

3-11. Revetment Toe Protection Design

The following guidance applies to several alternative methods of toe protection illustrated in Plate 43.

a. *Method A.* When toe excavation can be made in the dry, the riprap layer may be extended below the existing groundline a distance exceeding the anticipated depth of scour. If excavation quantities are prohibitive, the concept of Method D can be adapted to reduce excavation.

b. *Method B.* When the bottom of the channel is nonerodible material, the normal riprap should be keyed in at streambed level.

c. *Method C.* When the riprap is to be placed underwater and little toe scour is expected (such as in straight reaches that are not downstream of bends, unless stream is braided), the toe may be placed on the existing bottom with height a and width c equal to 1.5T and 5T, respectively. This compensates for uncertainties of underwater placement.

d. *Method D.* An extremely useful technique where water levels prohibit excavation for a toe section is to place a launchable section at the toe of the bank. Even if excavation is practicable, this method may be preferred for cost savings if the cost of extra stone required to produce a launched thickness equal to or greater than 1.5T is exceeded by the cost of excavation required to carry the design thickness T down the slope. This concept simply uses toe scour as a substitute for mechanical excavation. This method also has the advantage of providing a "built-in" scour gage, allowing easy monitoring of high-flow scour and the need for additional stone reinforcement by visual inspection of the remaining toe stone after the high flow subsides or by surveyed cros sections if the toe stone is underwater. It is readil adaptable to emergency protection, where high flow an the requirement for quick action make excavation imprac tical. Shape of the stone toe is not critical. For trench fill revetments, the height of the stone section is generall one-half to one times the length. For weighted ripra toes, heights as low as 2 times the bank protectio thickness have been used. Providing an adequate volum of stone is critical. To compute the required launchable stone volume for Method D, the following assumptions should be used:

(1) Launch slope = 1V on 2H. This is the slope resulting from rock launched on noncohesive material in both model and prototype surveys. Launch slope is less predictable if cohesive material is present, since cohesive material may fail in large blocks.

(2) Scour depth = existing elevation - maximum scour elevation.

(3) Thickness after launching = 1.5 times the thickness of the bank revetment T.

Using these assumptions, the
volume = 1.5T times launch slope length

= 1.5T times scour depth times $\sqrt{5}$

= 3.35T (scour depth)

Add a safety factor if data to compute scour depth are unreliable, if cohesive bank material is present, or if monitoring and maintenance after construction cannot be guaranteed. Guidance for a safety factor is lacking, so to some extent it must be determined by considering consequences of failure.

3-12. Delivery and Placement

Delivery and placement can affect riprap design. See EM 1110-2-2302 for detailed guidance. The common methods of riprap placement are hand placing; machine placing, such as from a skip, dragline, or some form of bucket; and dumping from trucks and spreading by bulldozer. Hand placement produces the most stable riprap revetment because the long axis of the riprap particles are oriented perpendicular to the bank. It is the most expensive method except when stone is unusually costly and/or labor unusually cheap. Steeper side slopes can be used with hand-placed riprap than with other placing methods. This reduces the required volume of rock. However, the

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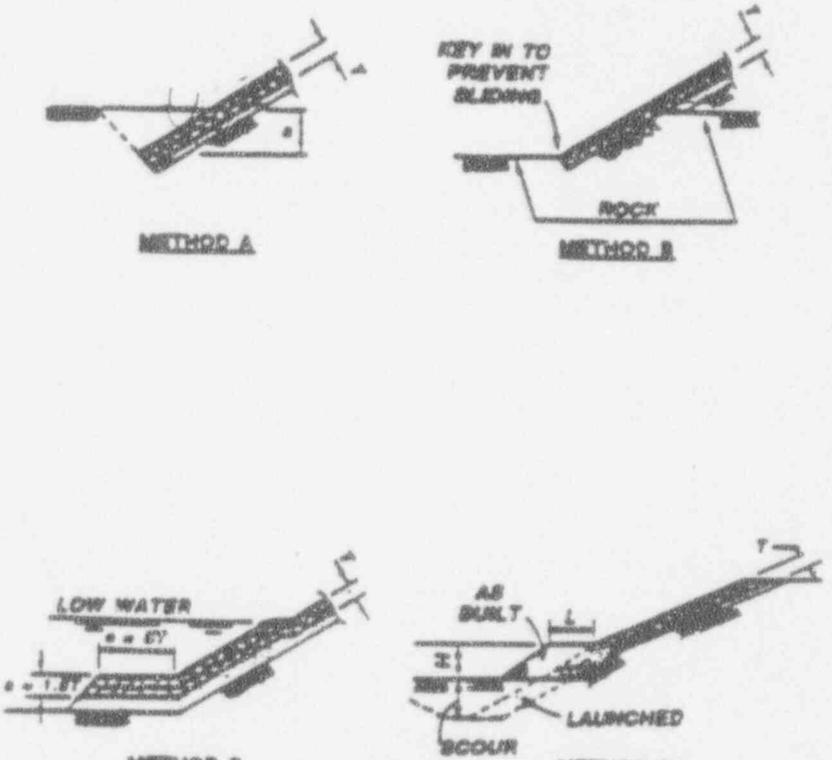

METHOD A

METHOD B

METHOD C

METHOD D

REVETMENT TOE PROTECTION

PLATE B-43

NUREG/CR-44
PNL-5724
RU

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Erosion Protection of Uranium Tailings Impoundments

Manuscript Completed: August 1986
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Prepared by
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Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN B2370

cannot satisfy these criteria, two or more filter layers may be necessary. The finer filter overlies the top layer of the radon suppression cover and the coarser filter lies between the finer filter and the riprap.

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The grain-size curve of the filter material should have a smooth s-shape without pronounced breaks and should be roughly parallel to the grain-size curve of the soil being protected, although other smooth shapes may be used.

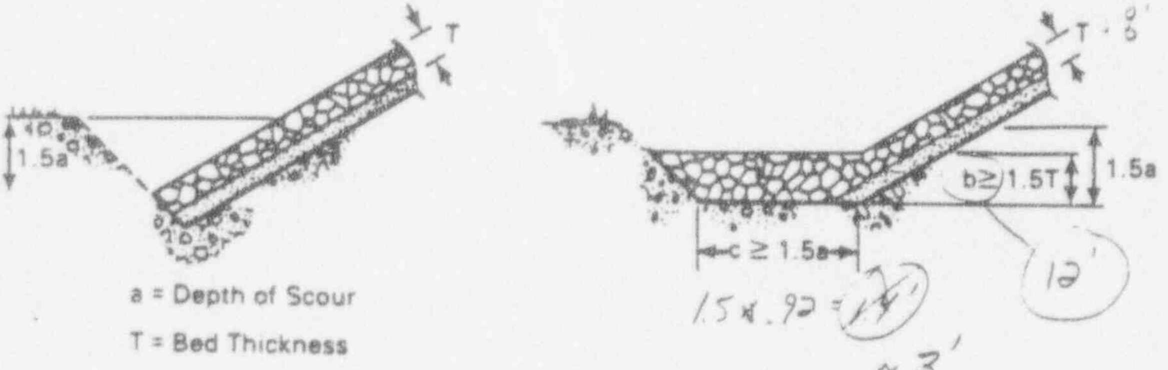
Thickness of Filter. The filter layer should have a minimum thickness of 12 in. and be at least equal to one-half the riprap layer thickness. Where two filter layers are required, the finer filter layer should have a minimum thickness of 12 in. and be at least equal to one-half the coarser filter layer thickness.

The use of these layer thicknesses assumes that the underlying radon suppression cover is structurally stable and capable of supporting the loads imposed by the construction equipment and the filter and riprap layers. If this is not the case, larger filter layer thicknesses may be needed to support construction equipment or the riprap. Larger filter layer thicknesses may also account for larger differential settlements caused by consolidation of the underlying materials. The greater layer thickness should be determined in the field based on the actual condition of the radon suppression cover.

Toe Protection

A riprap toe protection is required at the base of all impoundment side slopes. In general, the toe protection can be one of two types as shown in Figure 10.

For Method A, the riprap layer constructed on the slope may extend below grade to a depth of 1.5 times the estimated depth of scour at the impoundment perimeter. The angle of the below-grade protection may be steeper than the relatively flat slope angle, if the stability of the impoundment after scour is adequate. The sizing of the riprap is based on the actual slope used, assuming that the full design-estimated depth of scour has occurred.



Method A

Method B

FIGURE 10. Toe Protection Methods

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A second approach, Method B, includes a horizontal riprap toe. The width of the horizontal protection should be at least equal to the estimated depth of scour times 1.5. The thickness of the layer should be at least 1.5 times the thickness of the riprap on the slope.

Gully Erosion Protection

The remaining unprotected side slope surfaces above maximum flood elevation require protection from gully erosion. These surface areas are the most vulnerable to gullying because of their steepness. [illegible]ies are initiated, the process can proceed rapidly (one year or several years) toward a breach in the impoundment. Each impoundment will require some minimum thickness of rock riprap completely covering the side slopes for the purpose of preventing gully erosion. This will be the case regardless of whether flooding is a consideration. Because of the threat of this potentially destructive process, the application of rock riprap is recommended for the long-term protection of the side slopes. However, the problem is complicated by other factors.

Gullies that form from land surface depressions and rills can actively be prevented by rock riprap applied to the side slopes of impoundments since they are the direct result of overland flow. Gullies caused by differential settlement, slope failure, and piping cannot always be prevented by rock riprap because they are not the direct result of rainfall-runoff. However, in these situations, the presence of an engineered rock cover could mitigate the effects of these processes by self-adjustment of the rock cover itself. This would help prevent further erosion by surface runoff by the shifting of individual rocks to accommodate the new surface configuration. Although rock armor may prevent further damage caused by differential settlement, slope failure, and piping, it is best that preventive measures for these types of failures be considered in the design of the embankment foundation and earthen cover.

Design Suggestions for Gully Erosion Protection

A study by Walters and Skaggs (1986) determined that there are no procedures available to design rock riprap to protect against overland and gully erosion. The study results indicated that movement of runoff over a soil cover armored by rock may involve both interflow through the rock layer and filter and cascading flow over the rock surface. Not enough information is available at this time to indicate whether the movement of the runoff through the rock layer can be described by the equations of porous media flow. The interstitial voids in the rock layer can be extremely large and would allow runoff to move through rapidly.

The lack of information on the hydraulic roughness (Manning's n) for flow over the rock surface poses another problem. The results of field and laboratory testing are very limited for unprotected soil surfaces and nonexistent for rock surfaces. Therefore, the inability to predict the flow characteristics over and through the rock layer would limit any analysis to very rough assumptions.

ATTACHMENT B

SUPERCRITICAL HEC-2 RUN ON MOAB WASH

(ENTIRE CALC. BRIEF FOUND IN APPENDIX G OF 1992 ATLAS REC. PLAN)

C-75

By JWS Date 6/2/92 Subject HEC-2 MOAB WASH Sheet No. 41 of 69

Chkd. By Date 6/3/92 Proj. No 88-067-08

1/4" X 1/4"

HEC-2 OUTPUT FILE FOR
MOAB WASH SUPERCRITICAL RUN

Mc WASH - SUPERCRITICAL : 92

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Attachment C

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6/3/92

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********************************************       ****************************************
*  ER SURFACE PROFILES                       *     * U.S. ARMY CORPS OF ENGINEERS           *
*   ION OF SEPTEMBER 1988                    *     * THE HYDROLOGIC ENGINEERING CENTER      *
* ERROR: 01.02.03.04                         *     * 609 SECOND STREET, SUITE D             *
* UPDATED:  JUNE 1990                        *     * DAVIS, CALIFORNIA 95616-4687           *
* RUN DATE    5/15/92      TIME  17:04:36    *     *                                        *
********************************************       ****************************************


                    X     X XXXXXXX  XXXXX          XXXXX
                    X     X X       X     X        X     X
                    X     X X       X                    X
                    XXXXXXX XXXX    X       XXXXX   XXXXX
                    X     X X       X              X
                    X     X X       X     X        X
                    X     X XXXXXXX  XXXXX         XXXXXXX


                 :::::::::::::::::::::::::::::::::::::::::::::
                 :::::::::::::::::::::::::::::::::::::::::::::
                 :::                                       :::
                 :::   FULL MICRO-COMPUTER IMPLEMENTATION  :::
                 :::                                       :::
                 :::::::::::::::::::::::::::::::::::::::::::::
                 :::::::::::::::::::::::::::::::::::::::::::::


                          ============================
                            H A E S T A D  M E T H O D S
                          ============================

     37 Brookside Road  *  Waterbury, Connecticut  06708  *  (203) 755-1666


ND OF BANNER
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CKD [illegible] 8/3/92

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  Date:  5/15/92   Run Time: 17: 4:36   HMVersion: 5.30   Data File:  H:MW1.HC2
                                                                                  Page   1



                                                          THIS RUN EXECUTED  5/15/92   17: 4:36
 **********************************************
 HEC2 RELEASE DATED SEP 88 UPDATED JUN  1990


 ERROR CORR -  01.02.03.04
 MODIFICATION -
 **********************************************


 R
 1 PROBABLE MAXIMUM FLOOD - MOAB WASH
 2 ATLAS MINERALS 88-067 5/12/92
 3      MOAB WASH - SUPERCRITICAL

 1  ICHECK    INQ      NINV     IDIR     STRT     METRIC   HVINS    Q        WSEL     FQ

      0.       0.       0.       1.      .000      0.       .5    16129.   4006.3     0.

 C    0.03     0.03     0.03      0.       0.        0.       0.       0.       0.       0.
 1     8.       8.       1.7     520.     390.      425.     395.      0.       0.       0.
 R    04.       0.     4003.5     1.7    4003.5     15.5    4002.      0.       0.       0.
 R  4003.5    124.5    4003.5    520.    4034.      620.             20.     4002.     120.

 1     7.       8.       15.     529.5    430.      490.     440.
 R  4001.       0.     3996.5     15.    3996.5     35.     3995.      0.       0.       0.
 R  3996.5    144.     3996.5    529.5   4000.      540.             39.5    3995.     139.5

 1     6.       9.       30.     515.     600.      750.     615.      0.       0.       0.
 R  3999.       0.     3989.5     30.    3989.5     55.5    3988.     60.     3988.     160.
 R  3989.5    164.5    3989.5    515.    3996.      535.    3997.5    700.

 1     5.       9.       22.5    470.     800.      530.     750.      0.       0.       0.
 R  3991.       0.     3983.5     22.5   3983.5     35.5    3981.8    40.     3981.8    140.
 R  3983.5    144.5    3983.5    470.    3987.      480.5   3988.     580.

 1     4.       9.       35.     470.     850.      350.     560.      0.       0.       0.
 R  3988.       0.     3976.3     35.    3976.3     95.5    3974.6    100     3974.6    200.
 R  3976.3    204.5    3976.3    470.    3981.0     484.    3983.     670.

 1     3.       9.       67.     1093.    680.      500.     525.      0.       0.       0.
 R  3994.       0.     3971.7     67.    3971.7    515.5    3970.     520.    3970.     620.
 R  3971.7    625.     3971.7    1093.   3976.     1100.    3978.    1335.

 1     2.       8.       6.      1686.    540.      600.     520.      0.       0.       0.
 R  3970.      0.0     3968.      6.     3968.      730.    3967.     733.    3967.     883.
    3968.     886.     3968.     1686.   3971.     1692.
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Date:  5/15/92    Run Time: 17: 4:36    HMVersion: 5.30    Data File:   H:MW1.HC2
                                                                                     Page   2


1       1.        8.        6.     2180.      345.      860.      435.       0.        0.        0.
R    3968.        0.     3966.        6.     3966.      800.     3964.     806.     3964.     1071.
R    3966.     1077.     3966.     2180.     3968.     2186.

1       0.        8.        6.     2953.        0.        0.        0.       0.        0.        0.
R   3965.4        0.    3963.4        6.    3963.4     1000.    3961.4    1006.    3961.4     1220.
R   3963.4     1226.    3963.4     2953.    3965.4     2960.
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CLO
6/3/92

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CKD 6/3/92

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 - Date:  5/15/92    Run Time: 17: 4:36    HMVersion: 5.30    Data File:   H:MW1.HC2                     Page   3

   SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG        HV         HL        OLOSS     L-BANK ELEV
   Q          QLOB       QCH        QROB       ALOB       ACH       AROB       VOL       TWA       R-BANK ELEV
   TIME       VLOB       VCH        VROB       XNL        XNCH      XNR        WTN       ELMIN     SSTA
   SLOPE      XLOBL      X'',       XLOBR      ITRIAL     IDC       ICONT      CORAR     TOPWID    ENDST

*PROF 1


*SECNO 8.000
3280 CROSS SECTION      8.00 EXTENDED      2.28 FEET

3720 CRITICAL DEPTH ASSUMED
     8.000       4.28   4006.28   4006.28   4006.30   4007.84      1.56       .00        .00   4003.50
   16129.0       21.2   16036.2      72.6       4.3    1596.5      12.6        .0         .0   4003.50
       .00       4.94     10.04      5.74      .030      .030      .030      .000    4002.00       .00
   .009185         0.        0.        0.         0         4         0       .00     529.11    529.11

*SECNO 7.000

1645 INT SEC ADDED BY RAISING SEC      7.00,   5.25 FT AND MULTIPLYING BY   1.005


3301 HV CHANGED MORE THAN HVINS


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  1.57

     1.010       3.56   4003.81   4004.54       .00   4006.49      2.68      1.35        .00   4001.75
   16129.0       51.8   16030.9      46.3       7.0    1217.7       6.3       3.2        1.2   4001.75
       .00       7.35     13.17      7.31      .030      .030      .030      .000    4000.25      8.21
   .022574        98.       99.      106.         7         5         0       .00     530.12    538.32


1645 INT SEC ADDED BY RAISING SEC      1.01,  -1.750 FT AND MULTIPLYING BY    .998

     1.020       3.74   4002.24   4002.78       .00   4004.54      2.29      1.96        .00   4000.00
   16129.0       57.7   16019.8      51.6       8.4    1315.0       7.6       6.1        2.4   4000.00
       .00       6.86     12.18      6.81      .030      .030      .030      .000    3998.50      7.55
   .017408        98.       99.      106.         4        11         0       .00     530.46    538.01


1645 INT SEC ADDED BY RAISING SEC      1.02,  -1.750 FT AND MULTIPLYING BY    .998

        30       3.73   4000.48   4001.06       .00   4002.80      2.32      1.73        .00   3998.25
        .0       57.4   16020.4      51.3       8.3    1307.8       7.5       9.1        3.6   3998.25
       .01       6.86     12.25      6.85      .030      .030      .030      .000    3996.75      7.57
   .017693        98.       99.      106.         2         8         0       .00     529.52    537.09
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F-BC

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CKD JWB 6/3/.

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   SECNO    DEPTH   CWSEL    CRIWS    WSELK    EG       HV       HL       OLOSS    L-BANK ELEV
   Q        QLOB    QCH      QROB     ALOB     ACH      AROB     VOL      TWA      R-BANK ELEV
   TIME     VLOB    VCH      VROB     XNL      XNCH     XNR      WTN      ELMIN    SSTA
   SLOPE    XLOBL   XLCH     XLOBR    ITRIAL   IDC      ICONT    CORAR    TOPWID   ENDST


1645 INT SEC ADDED BY RAISING SEC      1.03.  -1.750 FT AND MULTIPLYING BY    .998

     7.000     3.72  3998.72  3999.31      .00  4001.05     2.33     1.75      .00  3996.50
   16129.0     57.3  16020.4     51.3      8.3   1305.3      7.5     12.1      4.8  3996.50
       .01     6.90    12.27     6.85     .030     .030     .030     .000  3995.00     7.56
   .017763      98.      99.     106.        0        8        0      .00   528.64   536.20

*SECNO 6.000  - L
     6.000     3.99  3991.99  3992.40      .00  3994.11     2.12     6.94      .00  3989.50
   16129.0     64.7  16001.3     63.0      9.8   1365.8      9.6     25.8     10.0  3989.50
       .02     6.60    11.72     6.58     .030     .030     .030     .000  3988.00    22.13
   .014085     430.     440.     490.        5       11        0      .00   500.54   522.67

*SECNO 5.000  - M
     20 TRIALS ATTEMPTED WSEL,CWSEL
   3 PROBABLE MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED
     5.000     4.70  3986.50  3986.50      .00  3988.20     1.71     6.79      .03  3983.50
   16129.0     79.3  15970.3     79.3     13.5   1518.1     13.5     46.5     16.9  3983.50
       .04     5.89    10.52     5.89     .030     .030     .030     .000  3981.80    13.51
   .008865     600.     615.     750.       20       11        0      .00   465.47   478.99

*SECNO 4.000  - N
     4.000     4.61  3979.21  3979.37      .00  3981.10     1.90     7.10      .00  3976.30
   16129.0     78.0  15973.4     77.6     12.6   1441.0     12.6     72.4     24.7  3976.30
       .05     6.18    11.08     6.18     .030     .030     .030     .000  3974.60    26.31
   .010160     800.     750.     530.        3        5        0      .00   452.34   478.65

*SECNO 3.000

1645 INT SEC ADDED BY RAISING SEC      3.00.   2.300 FT AND MULTIPLYING BY    .867


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE.  KRATIO =  1.40

     1.010     3.30  3975.60  3975.97      .00  3977.22     1.62     3.88      .00  3974.00
   16129.0     19.1  16100.5      9.4      3.3   1573.8      1.8     82.2     29.1  3974.00
       .06     5.75    10.23     5.26     .030     .030     .030     .000  3972.30    53.95
   .019961     425.     280.     175.        4       15        0      .00   896.18   950.13
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cco Tab 4.

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SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS     L-BANK ELEV
Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA       R-BANK ELEV
TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN     SSTA
SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID    ENDST


1645 INT SEC ADDED BY RAISING SEC      1.01.  -2.300 FT AND MULTIPLYING BY   1.153


3301 HV CHANGED MORE THAN HVINS

3685 20 TRIALS ATTEMPTED WSEL.CWSEL
3693 PROBABLE MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED
    3.000      3.47   3973.47   3973.47       .00   3974.40      1.01      4.04      3.35   3971.70
  16129.0      21.7   16096.3      11.0       4.7    1996.1       2.6      93.7      35.3   3971.70
      .07      4.61      8.06      4.29      .030      .030      .030      .000   3970.00     61.68
  .010920      425.      280.      175.        20         8         0       .00   1034.21   1095.88

*SECNO 2.000
3685 20 TRIALS ATTEMPTED WSEL.CWSEL
     PROBABLE MINIMUM SPECIFIC ENERGY
..20 CRITICAL DEPTH ASSUMED
    2.000      2.31   3969.31   3969.31       .00   3970.04       .72      6.04      3.79   3968.00
  16129.0      10.3   16112.1       6.6       2.6    2357.6       1.7     120.0      51.7   3968.00
      .09      3.98      6.83      3.82      .030      .030      .030      .000   3967.00      2.06
  .012119      680.      525.      500.        20        19         0       .00   1686.56   1688.62

*SECNO 1.000
3685 20 TRIALS ATTEMPTED WSEL.CWSEL
3693 PROBABLE MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED
    1.000      2.94   3966.94   3966.94       .00   3967.54       .60      6.39      5.99   3966.00
  16129.0       4.3   16120.4       4.3       1.3    2593.9       1.3     149.6      74.8   3966.00
      .12      3.23      6.21      3.23      .030      .030      .030      .000   3964.00      3.17
  .012444      540.      520.      600.        20        11         0       .00   2179.66   2182.83

*SECNO  .000
3685 20 TRIALS ATTEMPTED WSEL.CWSEL
3693 PROBABLE MINIMUM SPECIFIC ENERGY
3720 CRITICAL DEPTH ASSUMED
     .000      2.84   3964.24   3964.24       .00   3964.71       .48      5.49      6.35   3963.40
  16129.0       3.2   16122.6       3.2       1.0    2904.2       1.0     177.1     100.4   3963.40
      .14      3.03      5.56      3.03      .030      .030      .030      .000   3961.40      3.49
  .012812      345.      435.      860.        20        10         0       .00   2952.02   2955.51
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- P

6.82

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PROFILE FOR STREAM  MOAB WASH - SUPERCRITICA


PLOTTED POINTS (BY PRIORITY) E-ENERGY.W-WATER SURFACE.I-INVERT.C-CRITICAL W.S..L-LEFT BANK.R-RIGHT BANK.M-LOWER END STA


ELEVATION  3961.     3966.     3971.     3976.     3981.     3986.     3991.     3996.     4001.     4006.
    SECND   CUMDIS

    8.00      0.  .         .         .         .         .         .         .         .         .I  LM    W  E      .
             50.  .         .         .         .         .         .         .         .        I. L   MWC . E       .
    1.01    100.  .         .         .         .         .         .         .         .       I .L   WC M E         .
            150.  .         .         .         .         .         .         .         .     I  L.  WC M E .         .
    1.02    200.  .         .         .         .         .         .         .         .   I  L  .WCM  E   .         .
            250.  .         .         .         .         .         .         .         . I  L    WCM  E    .         .
    1.03    300.  .         .         .         .         .         .         .         .I  L   WC.M E      .         .
            350.  .         .         .         .         .         .         .        I. L   W CM.E        .         .
    7.00    400.  .         .         .         .         .         .         .     I   L    WCM E.         .         .
            450.  .         .         .         .         .         .         .     I  L.  WC ME  .         .         .
            500.  .         .         .         .         .         .         .   I L   .WC  E    .         .         .
            550.  .         .         .         .         .         .         . I  L   WC   E     .         .         .
            600.  .         .         .         .         .         .         .I  L    WC  EM     .         .         .
            650.  .         .         .         .         .         .        I. L    WC .E  M     .         .         .
            700.  .         .         .         .         .         .      I  .L   WC   E  M      .         .         .
            750.  .         .         .         .         .         .    I   L.  WC  E  . M       .         .         .
            800.  .         .         .         .         .         .   I  L  .WC    E  . M       .         .         .
    6.00    850.  .         .         .         .         .         .  I  L   .WC   E   . M       .         .         .
            900.  .         .         .         .         .         . I  L    WC   E    .M        .         .         .
            950.  .         .         .         .         .         .I  L    WC  E     M.         .         .         .
           1000.  .         .         .         .         .         I  L     W.   E   M .         .         .         .
           1050.  .         .         .         .         .        I.  L    W .  E  M   .         .         .         .
           1100.  .         .         .         .         .       I .L     W  .E  M     .         .         .         .
           1150.  .         .         .         .         .      I  L     W   E  M      .         .         .         .
           1200.  .         .         .         .         .     I  L.    W   E.M        .         .         .         .
           1250.  .         .         .         .         .    I  L .   W    EM         .         .         .         .
           1300.  .         .         .         .         .   I  L  .  W   EM .         .         .         .         .
           1350.  .         .         .         .         .  I  L   .W    EM  .         .         .         .         .
           1400.  .         .         .         .         . I  L    .W   E    .         .         .         .         .
    5.00   1450.  .         .         .         .         .I  L     W   ME    .         .         .         .         .
           1500.  .         .         .         .         I  L     W.  E      .         .         .         .         .
           1550.  .         .         .         .        I. L     W . E       .         .         .         .         .
           1600.  .         .         .         .       I .L     W  .E        .         .         .         .         .
           1650.  .         .         .         .      I  L     W   EM        .         .         .         .         .
           1700.  .         .         .         .     I  L.    W   EM         .         .         .         .         .
           1750.  .         .         .         .    I  L .   W   EM.         .         .         .         .         .
           1800.  .         .         .         .   I  L  . WC   E M.         .         .         .         .         .
           1850.  .         .         .         .  I   L  .WC   E M .         .         .         .         .         .
           1900.  .         .         .         . I   L   .WC  E M  .         .         .         .         .         .
           1950.  .         .         .         .I   L    WC  E  M  .         .         .         .         .         .
           2000.  .         .         .         I   L    WC  E  M   .         .         .         .         .         .
           2050.  .         .         .        I.  L     W. E  M    .         .         .         .         .         .
           2100.  .         .         .       I . L     W .E   M    .         .         .         .         .         .
           2150.  .         .         .      I  .L     W  E   M     .         .         .         .         .         .
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G-8:

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 4.00  2200. .         .         .     I   L     W  E.  M      .         .         .         .         .         .
       2250. .         .         .     I  L.   WC  E .M        .         .         .         .         .         .
       2300. .         .         .    I  L .  WC  E  .M        .         .         .         .         .         .
       2350. .         .         .   I  L  . W  E    M         .         .         .         .         .         .
       2400. .         .         .  I   L WC   E    M.         .         .         .         .         .         .
       2450. .         .         . I   L WC  E     M .         .         .         .         .         .         .
 1.01  2500. .         .         . I  L WC.  E     M .         .         .         .         .         .         .
       2550. .         .         .I  L   W        M  .         .         .         .         .         .         .
       2600. .         .         I   L W  L      M   .         .         .         .         .         .         .
       2650. .         .        I.  L W  E.     M    .         .         .         .         .         .         .
       2700. .         .        I. L  WC E .    M    .         .         .         .         .         .         .
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 3.00  2800. .         .      I .L   W E   .  M      .         .         .         .         .         .         .
       2850. .         .      I  L  W E    .M        .         .         .         .         .         .         .
       2900. .         .     I  L.  WE     M         .         .         .         .         .         .         .
       2950. .         .    I  L . W E    M.         .         .         .         .         .         .         .
       3000. .         .    I L .W  E   M  .         .         .         .         .         .         .         .
       3050. .         .   I  L  W E   M   .         .         .         .         .         .         .         .
       3100. .         .   I L  W.E  M     .         .         .         .         .         .         .         .
       3150. .         .  I  L  WE  M      .         .         .         .         .         .         .         .
       3200. .         .  I L  WE.M        .         .         .         .         .         .         .         .
       3250. .         .I L   W E.         .         .         .         .         .         .         .         .
 2.00  3300. .         .I L  WE  .         .         .         .         .         .         .         .         .
       3350. .         .I L W E  .         .         .         .         .         .         .         .         .
       3400. .         I L  WE   .         .         .         .         .         .         .         .         .
       3450. .        I. L W E   .         .         .         .         .         .         .         .         .
       3500. .        I. L WEM   .         .         .         .         .         .         .         .         .
       3550. .       I .L  WE    .         .         .         .         .         .         .         .         .
       3600. .       I .L WEM    .         .         .         .         .         .         .         .         .
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       4150. . I   LWE M         .         .         .         .         .         .         .         .         .
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  .00  4250. I   L WEM .         .         .         .         .         .         .         .         .         .
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                                                       THIS RUN EXECUTED  5/15/92    17: 4:56
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HEC2 RELEASE DATED SEP 88 UPDATED JUN  1990

ERROR CORR -  01.02.03.04
MODIFICATION -
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TE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

AB WASH - SUPERCRITICA

MMARY PRINTOUT TABLE  150

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   7.000  395.00      .00     .00  3995.00  16129.00  3998.72  3999.31  4001.05  177.63   12.27  1321.11  1210.18

   6.000  440.00      .00     .00  3988.00  16129.00  3991.99  3992.40  3994.11  140.86   11.72  1385.19  1359.04   L

   5.000  615.00      .00     .00  3981.80  16129.00  3986.50  3986.50  3988.20   88.65   10.52  1544.99  1713.03   M

   4.000  750.00      .00     .00  3974.60  16129.00  3979.21  3979.37  3981.10  101.60   11.08  1466.19  1600.17   N

   3.000  560.00      .00     .00  3970.00  16129.00  3973.47  3973.47  3974.48  109.20    8.05  2003.39  1543.47

   2.000  525.00      .00     .00  3967.00  16129.00  3969.31  3969.31  3970.04  121.19    6.83  2361.89  1465.13   P

   1.000  520.00      .00     .00  3964.00  16129.00  3966.94  3966.94  3967.54  124.44    6.21  2596.60  1445.89

    .000  435.00      .00     .00  3961.40  16129.00  3964.24  3964.24  3964.71  128.12    5.56  2906.32  1424.96
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Date: 5/15/92   Run Time: 17: 4:36   HMVersion: 5.30   Data File:  H:MW1.HC2          Page  7

TOAB WASH - SUPERCRITICA

SUMMARY PRINTOUT TABLE  150

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*      .000   16129.00   3964.24       .00     -2.71       .00   2952.02    435.00
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CKD JDS
6/3/92

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UMMARY OF ERRORS AND SPECIAL NOTES


UTION SECND=      8.000  PROFILE=  1  CRITICAL DEPTH ASSUMED

UTION SECND=      7.000  PROFILE=  1  INTERPOLATED X-SECTIONS USED

UTION SECND=      5.000  PROFILE=  1  CRITICAL DEPTH ASSUMED
UTION SECND=      5.000  PROFILE=  1  PROBABLE MINIMUM SPECIFIC ENERGY
UTION SECND=      5.000  PROFILE=  1  20 TRIALS ATTEMPTED TO BALANCE WSEL

UTION SECND=      3.000  PROFILE=  1  INTERPOLATED X-SECTIONS USED

UTION SECND=      2.000  PROFILE=  1  CRITICAL DEPTH ASSUMED
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UTION SECND=      2.000  PROFILE=  1  20 TRIALS ATTEMPTED TO BALANCE WSEL

UTION SECND=      1.000  PROFILE=  1  CRITICAL DEPTH ASSUMED
UTION SECND=      1.000  PROFILE=  1  PROBABLE MINIMUM SPECIFIC ENERGY
UTION SECND=      1.000  PROFILE=  1  20 TRIALS ATTEMPTED TO BALANCE WSEL

U      ECND=       .000  PROFILE=  1  CRITICAL DEPTH ASSUMED
UT... SECND=       .000  PROFILE=  1  PROBABLE MINIMUM SPECIFIC ENERGY
UTION SECND=       .000  PROFILE=  1  20 TRIALS ATTEMPTED TO BALANCE WSEL

rmal program termination
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ATTACHMENT C

EXCERPTS FROM PEMBERTON, et. al.

"COMPUTING DEGRADATION AND LOCAL SCOUR"

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COMPUTING DEGRADATION AND LOCAL SCOUR

by

Ernest L. Pemberton
Joseph M. Lara

TECHNICAL GUIDELINE FOR
BUREAU OF RECLAMATION

SEDIMENTATION AND RIVER HYDRAULICS SECTION
HYDROLOGY BRANCH
DIVISION OF PLANNING TECHNICAL SERVICES
ENGINEERING AND RESEARCH CENTER

DENVER, COLORADO

JAN~~UARY~~ 1984

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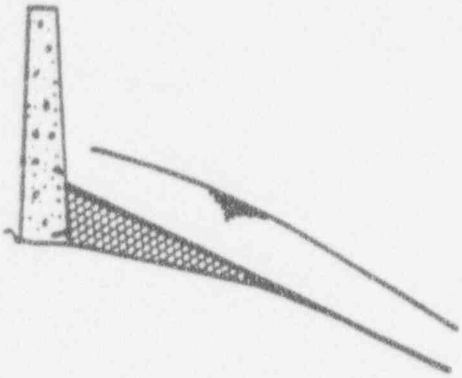

COMPUTING DEGRADATION AND LOCAL SCOUR

TECHNICAL GUIDELINE FOR BUREAU OF RECLAMATION

U.S. Department of the Interior
Bureau of Reclamation

Inch-pound units

$$L_g = \frac{37.05}{0.00112}$$

$$L_g = 33\,100 \text{ ft}$$

Metric units

$$L_g = \frac{1.625\ (6.94)}{0.00112}$$

$$L_g = 10\,100 \text{ m}$$

and for the subreaches:

Inch-pound units

$$L_1 = \frac{22.8}{2\ (0.00112)} = 10\,200 \text{ ft}$$

$$L_2 = \frac{3\ (22.8)}{8\ (0.00112)} = 7\,600 \text{ ft}$$

$$L_3 = \frac{3\ (22.8)}{4\ (0.00112)} = 15\,300 \text{ ft}$$

Metric units

$$L_1 = \frac{6.94}{2\ (0.00112)} = 3\,100 \text{ m}$$

$$L_2 = \frac{3\ (6.94)}{8\ (0.00112)} = 2\,300 \text{ m}$$

$$L_3 = \frac{3(6.94)}{4\ (0.00112)} = 4\,700 \text{ m}$$

CHANNEL SCOUR DURING PEAK FLOODFLOWS

The design of any structure located either along the riverbank and flood plain or across a channel requires a river study to determine the response of the riverbed and banks to large floods. A knowledge of fluvial morphology combined with field experience is important in both the collection of adequate field data and selection of appropriate studies for predicting the erosion potential. In most studies, two processes must be considered, (1) natural channel scour, and (2) scour induced by structures placed by man either in or adjacent to the main river channel.

Natural scour occurs in any moveable bed river but is more severe when associated with restrictions in river widths, caused by morphological channel changes, and influenced by erosive flow patterns resulting from channel alinement such as a bend in a meandering river. Rock outcrops along the bed or banks of a stream can restrict the normal river movement and thus effect any of the above influencing factors. Manmade structures can have varying degrees of influence, usually dependent upon either the restriction placed upon the normal river movement or by turbulence in flow pattern directly related to the structure. Examples of structures that influence river movement would be (1) levees placed to control flood plain flows, thus increasing main channel discharges; (2) spur dikes, groins, riprapped banks, or bridge abutments used to control main channel movement; or (3) pumping plants or headworks to canals placed on a riverbank. Scour of the bed or banks caused by these structures is that created by higher local velocities or excessive turbulence at the strucutre. Structures placed directly in the river consist of (1) piers and piling for either highways or railroad bridges; (2) dams across the river for diversion or storage, (3) grade control structures such as rock cascades, gabion controls or concrete baffled apron drop

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structures; or (4) occasionally a powerline or tower structure placed in the flood plain but exposed to channel erosion with extreme shifting or movement of a river. All of the above may be subject to higher local velocities, but usually are subject to the more critical local scour caused by turbulence and helicoidal flow patterns.

The prediction of river channel scour due to floods is necessary for the design of many Reclamation structures. These Reclamation guidelines on scour represent a summary of some of the more applicable techniques which are described in greater detail in the reference publications by T. Blench (1969), National Cooperative Highway Research Program Synthesis 5 (1970), C. R. Neill (1973), D. B. Simons and F. Senturk (1977), and S. C. Jain (1981). The paper by S. C. Jain (1981) summarized many of the empirical equations developed for predicting scour of a streambed around a bridge pier. It should be recognized that the many equations are empirically developed from experimental studies. Some are regime-type based on practical conditions and considerable experience and judgment. Because of the complexity of scouring action as related to velocity, turbulence, and bed materials, it is difficult to prescribe a direct procedure. Reclamation practice is to compute scour by several methods and utilize judgment in averaging the results or selection of the most applicable procedures.

The equations for predicting local channel scour usually can be grouped into those applicable to the two previously described processes of either a natural channel scour or scour caused by a manmade structure. A further breakdown of these processes is shown in table 6 where Type A equations are those used for natural river erosion and Types B, C, and D cover various manmade structures.

The importance of experience and judgment in conducting a scour study cannot be overemphasized. It should be recognized that the techniques described in these guidelines merely provide a set of practical tools in guiding the investigator to estimate the amount of scour for use in design. The collection of adequate field data to define channel hydraulics and bed or bank materials to be scoured govern the accuracy of any study. They should be given as much emphasis as the methodology used in the analytical study. Field data are needed to compute water surface profiles for a reach of river in the determination of channel hydraulics for use in a scour study. With no restrictions in channel width, scour is computed from the average channel hydraulics for a reach. If a structure restricts the river width, scour is computed from the channel hydraulics at the restriction. In all cases, scour estimates should be based upon the portion of discharge in and hydraulic characteristics of the main channel only.

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Table 6. - Classification of scour equation for various structure designs

Equation type	Scour	Design
A	Natural channel for restrictions and bends	Siphon crossing or any buried pipeline. Stability study of a natural bank. Waterway for one-span bridge.
B	Bankline structures	Abutments to bridge or siphon crossing. Bank slope protection such as riprap, etc. Spur dikes, groins, etc. Pumping plants. Canal headworks.
C	Midchannel structures	Piling for bridge. Piers for flume over river. Powerline footings. Riverbed water intake structures.
D	Hydraulic structures across channel	Dams and diversion dams. Erosion controls. Rock cascade drops, gabion controls, and concrete drops.

Although each scour problem must be analyzed individually, there are some general flow and sediment transport characteristics to be considered in making the judgmental decision on methodology. The general conclusion reached by Lane and Borland (1954) was that floods do not cause a general lowering of streambed, and rivers such as the Rio Grande may scour at the narrow sections but fill up at the wider downstream sections during a major flood. Another general sediment transport characteristic is the influence of a large sediment load on scour which includes the variation of sediment transport associated with a high peak, short duration flood hydrograph. The large sediment concentrations usually of clay and silt size material will occur on the rising stage of the hydrograph up and through the peak of the flood while the falling stage of the flood with deposition of coarser sediments in the bed of the channel may be accompanied by greater scour of the wetted channel banks. Channel scour also occurs when the capacity of streamflow with extreme high velocities in portions of the channel cross section will transport the bed material at a greater rate than replacement materials are supplied. Thus, maximum depth of channel scour during the flood is a function of the channel geometry, obstruction created by a structure (if any), the velocity of flow, turbulence, and size of bed material.

Design Flood

The first step in local scour study for design of a structure is selection of design flood frequency. Reclamation criteria for design of most structures

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shown in table 6 varies from a design flood estimated on a frequency basis from 50 to 100 years. This pertains to an adequate waterway for passage of the floodflow peak. The scour calculations for these same structures are always made for a 100-year flood peak. The use of the 100-year flood peak for scour is based on variability of channel hydraulics, bed material, and general complexity of the erosive process. The exception in the use of the 100-year flood peak for estimating scour would be the scour hole immediately below a large dam or a major structure where loss of structure could involve lives or represent a catastrophic event. In this case, the scour for use in design should be determined for a flow equal to 50 percent of the structure design flood.

Equation Types A and B (See Table 6)

Natural river channel scour estimates are required in design of a buried pipe, buried canal siphon, or a bankline structure. For most siphon crossings of a river, the cost of burying a siphon will dictate either the selection of a natural narrow reach of river or a restriction in width created by constructing canal bankline levees across a portion of the flood plain. A summary of available methods for computing scour at constrictions is given by Neill (1973). The four methods for estimating general scour at constricted waterways described by Neill (1973) are considered the proper approach for estimating scour for use in either design of a siphon crossing or where general scour is needed of the riverbed for a bankline structure. The four methods supplemented with Reclamation's procedure for application are given below:

Field measurments of scour method. - This method consists of observing or measuring the actual scoured depths either at the river under investigation or a similar type river. The measurements are taken during as high a flow as possible to minimize the influence of extrapolation.

A Reclamation unpublished study by Abbott (1963) analyzed U.S. Geological Survey discharge measurement notes from several streams in the southwestern United States, including the Galisteo Creek at Domingo, New Mexico, and developed an empirical curve enveloping observed scour at the gaging station. This envelope curve for use in siphon design was further supported by observed scour from crest-stage and scour gages on Gallegos, Kutz, Largo, Chaco, and Gobernador Canyons in northwest New Mexico collected during the period from 1963 to 1969. The scour gages consisted of a series of deeply anchored buried flexible tapes across the channel section that were resurveyed after a flood to determine the depth of scour at a specific location. The results of these measurements are shown on figure 8 along with the envelope curve for Galisteo Creek that support scour estimates for wide sandbed (D_{50} varying from 0.5 to 0.7 mm) ephemeral streams in the southwestern United States by the equation.

$$d_s = K\ (q)^{0.24} \tag{24}$$

where:

d_s = Depth of scour below streambed, ft (m)
K = 2.45 inch-pound units (1.32 metric units)
q = Unit water discharge, ft^3/s per ft of width (m^3/s per m of width)

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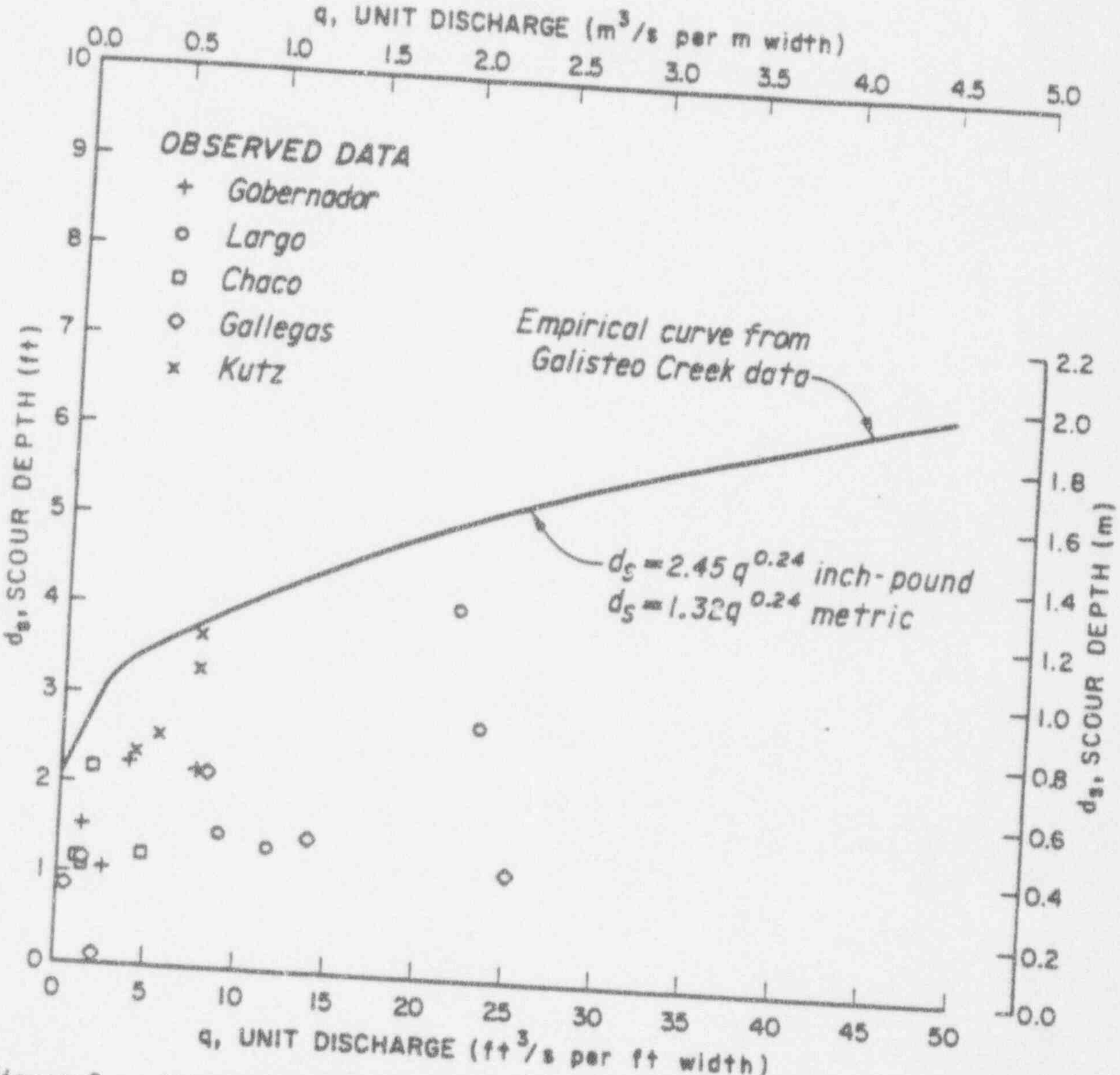

Figure 8. - Navajo Indian Irrigation Project - scour versus unit discharge.

The use of equation 24 except as a check on other methods would be limited to channels similar to those observed on relatively steep slopes ranging from 0.004 to 0.008 ft/ft (m/m). Because of shallow depths of flow and medium to coarse sand size bed material the bedload transport should also be very high.

Regime equations supported by field measurements method. - This approach as suggested by Neill (1973) on recommendations by Blench (1969) involves obtaining field measurements in an incised reach of river from which the bankfull discharge and hydraluics can be determined. From the bankfull hydraulics in the incised reach of river, the flood depths can be computed by:

$$d_f = d_i \left(\frac{q_f}{q_i}\right)^m \qquad (25)$$

where:

d_f = Scoured depth below design floodwater level
d_i = Average depth at bankfull discharge in incised reach
q_f = Design flood discharge per unit width
q_i = Bankfull discharge in incised reach per unit width
m = Exponent varying from 0.67 for sand to 0.85 for coarse gravel

This method has been expanded for Reclamation use to include the empirical regime equation by Lacey (1930) and the method of zero bed-sediment transport by Blench (1969) in the form of the Lacey equation:

$$d_m = 0.47 \left(\frac{Q}{f}\right)^{1/3} \qquad (26)$$

where:

d_m = Mean depth at design discharge, ft (m)
Q = Design discharge, ft^3/s (m^3/s)
f = Lacey's silt factor equals 1.76 $(D_m)^{1/2}$ where D_m equal mean grain size of bed material in millimeters

and the Blench equation for "zero bed factor":

$$d_{fo} = \frac{q_f^{\;2/3}}{F_{bo}^{\;1/3}} \qquad (27)$$

where:

d_{fo} = Depth for zero bed sediment transport, ft (m)
q_f = Design flood discharge per unit width, ft^3/s per ft (m^3/s per m)
F_{bo} = Blench's "zero bed factor" in ft/s^2 (m/s^2) from figure 9

The maximum natural channel scour depth for design of any structure placed below the streambed (i.e., siphon) or along the bank of a channel must

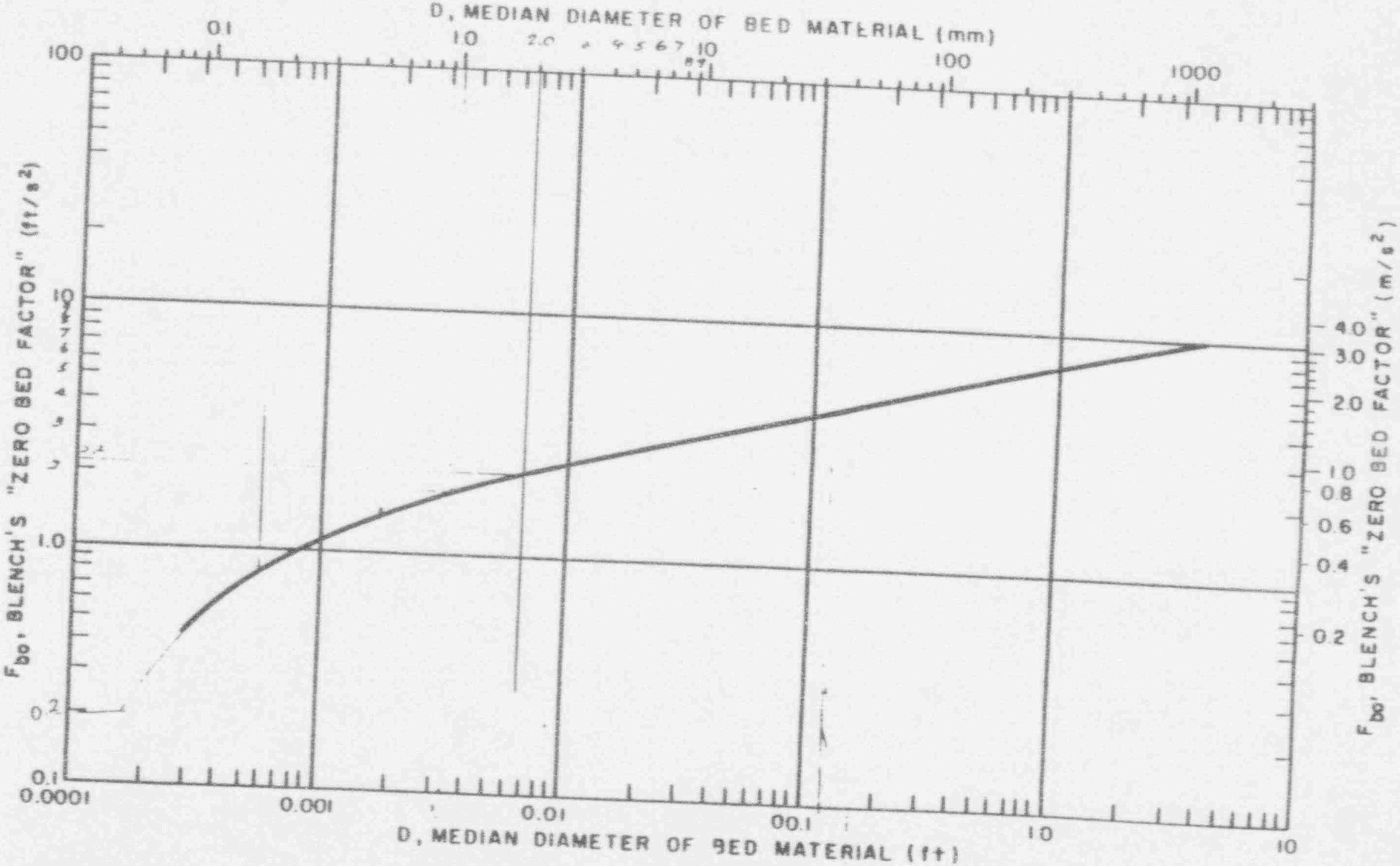

CHART FOR ESTIMATING F_{bo} (AFTER BLENCH)

Figure 9. - Chart for estimating F_{bo} (after Blench, 1969).

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consider the probable concentration of floodflows in some portion of the natural channel. Equations 25, 26, or 27 for predicting this maximum depth are to be adjusted by the empirical multiplying factors, Z, shown for formula Types A and B (table 6), in table 7. An illustration of maximum scour depth associated with a flood discharge is shown in a sketch of a natural channel, figure 10. As shown in table 7 and on figure 10, the d_s equals depth of scour below streambed.

$$d_s = Z\, d_f \tag{28}$$

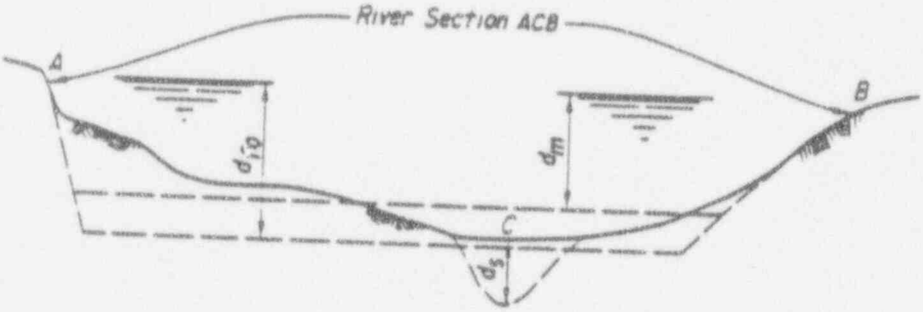
$$d_s = Z\, d_m \tag{29}$$

$$d_s = Z\, d_{fo} \tag{30}$$

Table 7. - Multiplying factors, Z, for use in scour depths by regime equations

Condition	Value of Z Neill $d_s = Z\,d_f$	 Lacey $d_s = Z\,d_m$	 Blench $d_s = Z\,d_{fo}$
Equation Types A and B			
Straight reach	0.5	0.25	1/ 0.6
Moderate bend	0.6	0.5	
Severe bend	0.7	0.75	
Right angle bends		1.0	
Vertical rock bank or wall		1.25	1.25
Equation Types C and D			
Nose of piers	1.0		0.5 to 1.0
Nose of guide banks	0.4 to 0.7	1.50 to 1.75	1.0 to 1.75
Small dam or control across river		1.5	0.75 to 1.25

1/ Z value selected by USBR for use on bends in river.



NOTE: $d_{fo} > d_f > d_m$. Point C is low point of natural section.

Figure 10. - Sketch of natural channel scour by regime method.

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Although not shown on figure 10, the d_f from Neill's equation 25 is usually less than the d_{fo} from Blench's equation 27 but greater than the d_m from Lacey's equation 26.

The design of a structure under a river channel such as a siphon is based on applying the scoured depth, d_s, as obtained from table 7 to the low point in a surveyed section, as shown by point C on figure 10. This criteria is considered by Reclamation as an adequate safety factor for use in design. In an alluvial streambed, designs should also be based on scour occuring at any location in order to provide for channel shifting with time.

Mean velocity from field measurements method. - This approach represents an adjustment in surveyed channel geometry based on an extrapolated design flow velocity. In Reclamation's application of this method, a series of at least four cross sections are surveyed and backwater computations made for the design discharge by use of Reclamation's Water Surface Profile Computer Program. In addition to the surveyed cross sections observed, water surface elevations at a known or measured discharge are needed to provide a check on Manning's "n" channel roughness coefficient. This procedure allows for any proposed waterway restrictions to be analyzed for channel hydraulic characteristics including mean velocity at the design discharge. The usual Reclamation application of this method is to determine the mean channel depth, d_m, from the computer output data and apply the Z values defined by Lacey in table 7 to compute a scour depth, d_s, by equation 29 where $d_s = Z\ d_m$.

Examples of more unique solutions to scour problems were Reclamation studies on the Colorado River near Parker, Arizona, and Salt River near Granite Reef Diversion Dam, Arizona, where an adjustment in "n" based on particle size along with a Z value from table 7 provided a method of computing bed scour. The selection of a particle size "n" associated with scour in the above two examples was computed from the Strickler (1923) equation for roughness of a channel based on diameter of particles where:

$$K = \frac{C}{D_{90}^{1/6}} \tag{31}$$

$C \approx 26$ from Nikuradse (1933) and "n" = 1/K. The appropriate "n" values for the two rivers based on particle size and engineering judgment were selected as follows:

River	D (mm)	Particle size "n"	Selected "n"
Colorado	0.2	0.01	0.014
Salt	18	0.02	0.02

In the Colorado River study, the existing channel "n" value of 0.022 was adjusted down to 0.014 due to bed material particle size to give a computed water surface at design discharge representative of a scoured channel. With a Z value of 0.5, the scoured section in the form of a trianglular section combined with the accepted "n" of 0.022 provided a close check on the water surface computed without scour. An illustration of this technique is shown in sketch on figure 11a. Another example is shown on figure 11b for a Salt River scour study where the particle size "n" of 0.02 gave a reduced mean depth. Scour was assumed to be in the shape of a triangle where the average depth of scour would be equal the depth at an "n" equal to 0.02 subtracted from depth at an "n" equal to 0.03. (See example problem in subsequent paragraph.)

4 Competent or limiting velocity control to scour method. - This method assumes that scour will occur in the channel cross section until the mean velocity is reduced to that where little or no movement of bed material is taking place. It gives the maximum limit to scour existing in only the deep scour hole portion of the channel cross section and is similar to the Blench equation 27 for a "zero bed factor."

The empirical curves, figure 12, derived by Neill (1973) for competent velocity with sand or coarser bed material (>0.30 mm) represent a combining of regime criteria, Shields (1936) criterion for material >1.0 mm, and a mean velocity formula relating mean velocity V_m to the shear velocity. The competent velocities for erosion of cohesive materials recommended by Neill (1973) are given in table 8. The scour depth or increase in area of scoured channel section with corresponding increase in depth for competent velocity, V_c, is determined by relationship of mean velocity, V_m, to V_c in the equation:

$$d_s = d_m \left(\frac{V_m}{V_c} - 1 \right) \qquad (32)$$

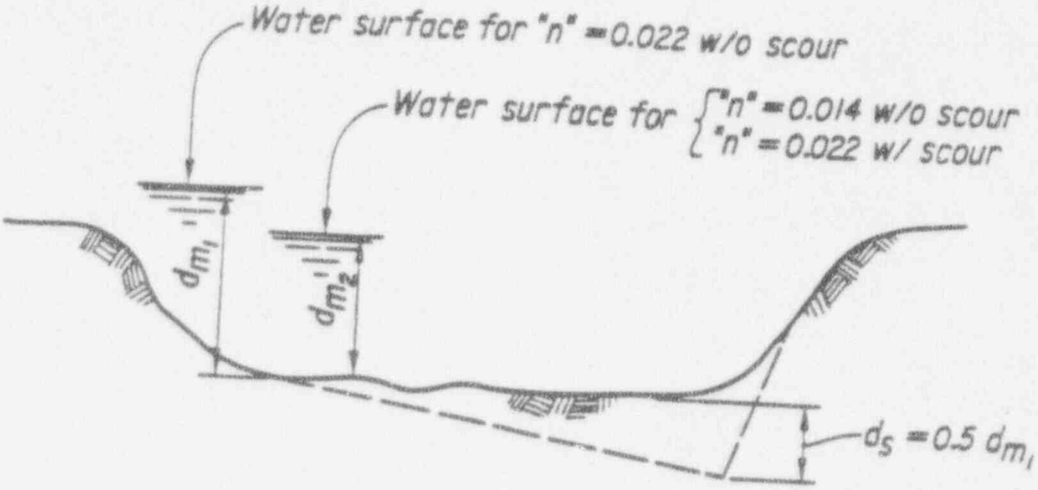
where:

d_s = Scour depth below streambed, ft (m)
d_m = Mean depth, ft (m)

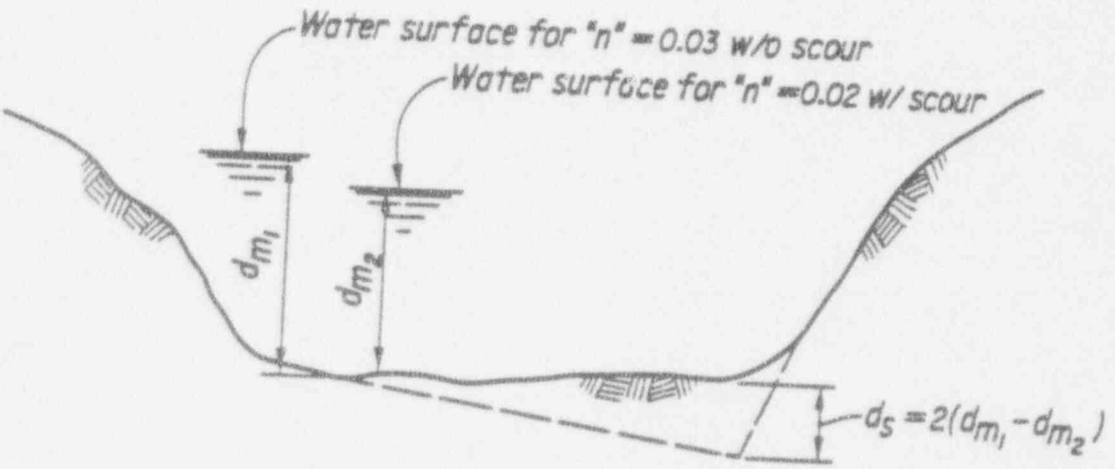
Table 8. - Tentative guide to competent velocities for erosion of cohesive materials* (after Neill, 1973)

Depth of flow		Competent mean velocity					
		Low values - easily erodible material		Average values		High values - resistant material	
ft	m	ft/s	m/s	ft/s	m/s	ft/s	m/s
5	1.5	1.9	0.6	3.4	1.0	5.9	1.8
10	3	2.1	0.65	3.9	1.2	6.6	2.0
20	6	2.3	0.7	4.3	1.3	7.4	2.3
50	15	2.7	0.8	5.0	1.5	8.6	2.6

* Notes: (1) This table is to be regarded as a rough guide only, in the absence of data based on local experience. Account must be taken of the expected condition of the material after exposure to weathering and saturation. (2) It is not considered advisable to relate the suggested low, average, and high values to soil shear strength or other conventional indices, because of the predominating effects of weathering and saturation on the erodibility of many cohesive soils.



a. Colorado River Study



b. Salt River Study

Figure 11. - Sketch of scour from water surface profile computations and reduced "n" for scour.

The use of figure 12 and table 8 recommended by Neill (1973) has had limited application in Reclamation, but appears to be a potential useful technique for many Reclamation studies on scour and armoring of the channel.

Equation Type C (See Table 6)

The principal references for design of midchannel structures for scour such as at bridge piers are National Cooperative Highway Research Program Synthesis 5 (1970), C. R. Neill (1973), Federal Highway Administration, Training and Design Manual (1975), Federal Highway Administration (1980), and S. C. Jain (1981). The numerous empirical relationships for computing scour at bridge piers include one or more of the following hydraulic parameters: pier width and skewness, flow depth, velocity, and size of sediment. The many relations available were further broken down by Jain (1981) to two different approaches: (1) regime, and (2) rational.

The Federal Highway Administration has funded numerous research projects to assist in improving their designs of bridge piers. This research has not resulted in any one recommended procedure. Reclamation's need for scour estimates at midchannel structures is limited. The procedures adopted are to try at least two techniques and apply engineering judgment in selecting an average or most reliable method. The regime approach is to use either equations 26, 27, 28, or 30 and a Z value from table 7. An appropriate Z value to use for piers is 1.0 as found for the railway bridge piers applied to the Lacey equation 29 reported by Central Board of Irrigation and Power (1971).

The rational equation selected for scour at piers is described by Jain (1981) in the form:

$$\frac{d_s}{b} = 1.84 \left(\frac{d}{b}\right)^{0.3} \left(F_c\right)^{0.25} \qquad (33)$$

where:

d_s = Depth of scour below streambed, ft (m)
b = Pier size, ft (m)
d = Flow depth, ft (m)
$F_c = V_c/\sqrt{gd}$ = Threshold Froude number
V_c = Threshold velocity, ft/s (m/s) from figure 12
g = Acceleration due to gravity, 32.2 ft/s^2 (9.81 m/s^2)

Equation Type D (See Table 6)

Immediately downstream from any hydraulic structure the riverbed is subject to the erosive action created by the structure. Some type of stilling basin or energy dissipator as described by Reclamation (1977) is provided in the design of such structures to dissipate the energy thereby reducing the erosion potential. There still remains at most structures, below the point where the structure ends and the natural riverbed material begins, a potential for scour. The magnitude of this scour hole will depend on a combination of flow velocity, turbulence, and vortices generated by the structure. Simons and Senturk (1977) describe many of the available equations.

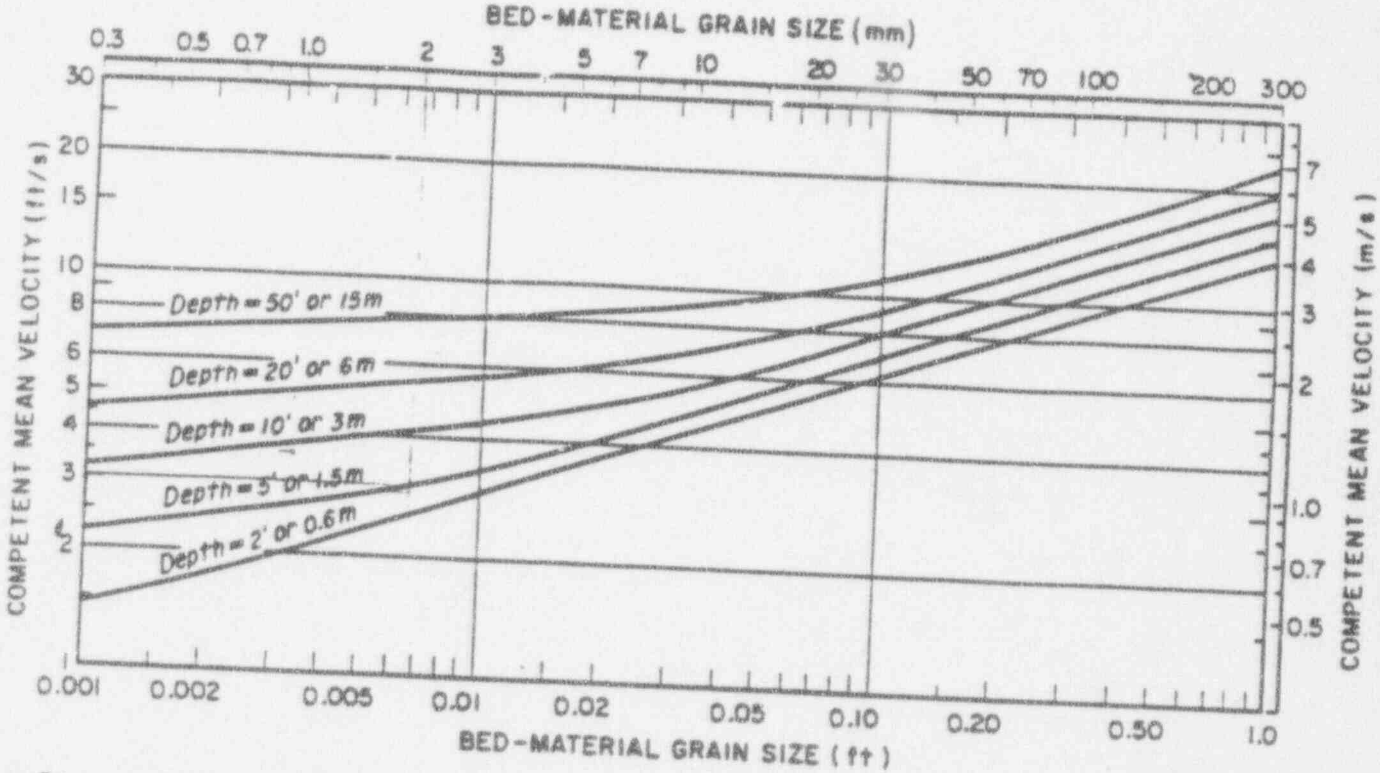


Figure 12. - Suggested competent mean velocities for significant bed movement of cohesionless materials, in terms of grain size and depth of flow (after Neill, 1973).