TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE CASPER, WYOMING SOIL CONSERVATION SERVICE

Engineering No. 13 April 21, 1975

Slope Staking & Earthwork Computations

General

It is advisable that methods of computing earthwork quantities and slope staking be as uniform as possible within the state. Contractors should expect this consistency to avoid confusion and possible disagreement on payment quantities and slope stake notation.

Earthwork Computation

The attached material provides a method for computation of earth work quantities. Method 1 is the most common procedure in use and is applicable for X-sections with uniform foundation slopes. Method 2 is applicable when the X-section has multiple breaks in the foundation ground surface. Method 3 is applicable with multiple foundation breaks and with X-sections requiring berms or varible side slopes.

The computation of volumes for pits involves the use of the prismoidal formula. This procedure is found in the Engineering Field Manual, Chapter 11, Ponds and Reservoirs.

In the computation of quantities for earth fill, such as in dams and dikes, the volume will include the following:

1. Dam or dike.
2. Allowance for settlement.
3. Backfill for stripping of foundation materials.
4. Backfill for the cutoff trench.
5. Fill for existing stream channels and holes in the foundation.
6. Any other fill the Contractor is required to perform.

The volume included for settlement in earth fill sections with relative uniform ground surface (maximum 20% variation in fill depths) may be calculated by multiplying the volume of the dam times the required percent of overfill. The only accurate way of computing overfill is including it in the calculations for earth fill sections using constructed slopes rather than design slopes.

The volume for stripping is best included in the fill computation by slope staking after stripping has been performed. This may be impractical for jobs where the stripping depth and quantity are small. In such cases, slope stakes can be set on original ground and stripping performed to the specified depth inside the staked area. The stripping quantity is then computed separately using the horizontal distance between toe stakes and the specified depth to compute end areas.

Volume Computation

Most SCS earthwork computation forms are set up to use double end area values. If the double end areas of adjacent sections are averaged and taken times the distance between, the resulting value must be divided

by 54 to obtain cubic yards. If the double end areas of adjacent sections are not averaged but summed, before multiplying times the distance between sections, the resulting value must be divided by 108 to obtain cubic yards. If actual end areas are computed and averaged, use 27 as the divisor.

Slope Staking

The method for setting slope stakes will be as shown in the Engineering Field Manual, Chapter 1, Page 1-47. Any additional markings on the stakes will be done only at the builder's request and with his full knowledge.

The slope stakes set at the toe of the fill will include the overfill height.

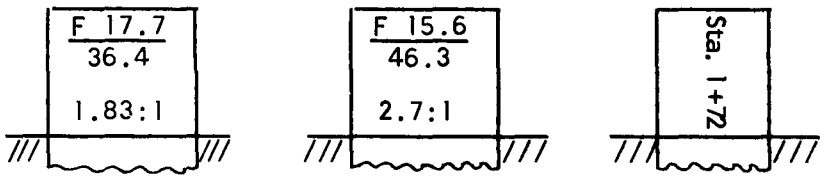
Example: Top width = 8.0'

X-Section = $\frac{F\ 16.2}{36.4}$ $\frac{F\ 14.9}{0.0}$ $\frac{F\ 14.1}{46.3}$

Overfill = 10% of ℄ Height.

Overfill = (0.10)(14.9) = 1.49 (Use 1.5 feet.)

Slope Stake Markings, Earth Fill



Back Toe Stake Front Toe Stake Back Side of Slope Stake

Side slope shown on the slope stake is the constructed slope. The constructed slope for earth fill of any X-section may be calculated as follows:

Distance from ℄ — $\frac{\text{Top Width}}{2}$ ÷ Total Fill Height.

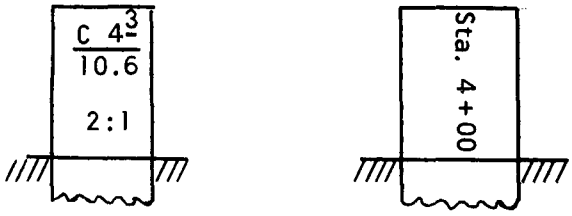
For the Example:

Back Slope: $\frac{(36.4 - 4)}{17.7}$ = 1.83:1

Front Slope: $\frac{(46.3 - 4)}{15.6}$ = 2.71:1

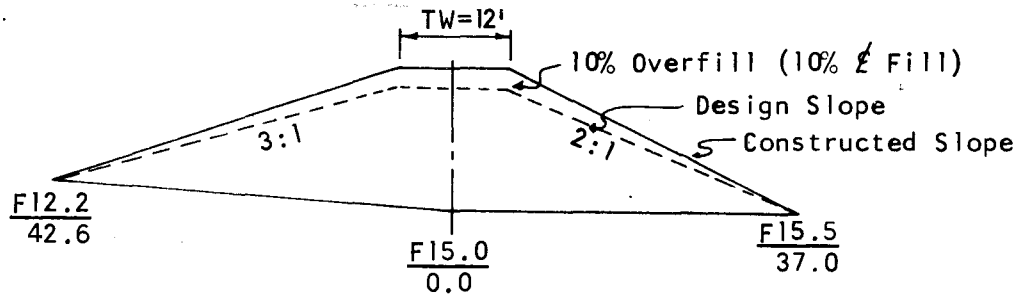
The constructed slope marked on the stake is used to check compliance, set additional construction stakes, or check slopes during construction. The constructed slope for earth fill will be placed on all slope stakes for dams with a fill of 20 feet or more. This is optional for smaller dams. The side slope for cut sections will be marked on the slope stakes.

Slope Stake Markings, Excavation:



Facing Cut Back Side of Slope Stake

METHOD 1



METHOD TO DETERMINE END AREAS:

Sum of the distances from ℄ to toe times the ℄ fill, plus the fills at the toe times $\frac{1}{2}$ the top width equals the double end area.

$$H\ (D_1 + D_2) + \frac{TW}{2}\ (H_1 + H_2) = 2 \times \text{Area}$$

When including the allowance for settlement in the calculations, use the fill plus overfill on all fill heights.

FILL:

$\frac{12.2}{42.6}$ $\frac{15.0}{0.0}$ $\frac{15.5}{37.0}$

$15\ (42.6 + 37.0) = 1194.0$

$\frac{12}{2}\ (12.2 + 15.5) = 166.2$

1360.2 = Double End Area

The total double end area including an additional 10% for settlement = (1.1) (1360.2) = 1496.2.

FILL WITH ALLOWANCE FOR SETTLEMENT

$\frac{13.7}{42.6}$ $\frac{16.5}{0.0}$ $\frac{17.0}{37.0}$

$16.5\ (42.6 + 37.0) = 1313.4$

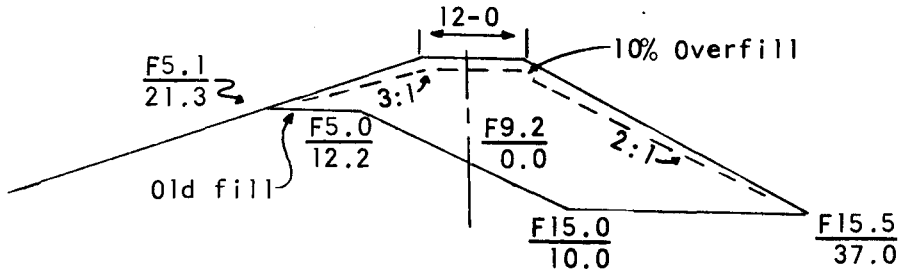
$\frac{12}{2}\ (13.7 + 17.0) = 184.2$

1497.6 = Double End Area

This method of calculating allowance for settlement as part of the fill is accurate and preferred over adding 10% directly.

METHOD 2

MULTIPLE SECTIONS



METHOD TO DETERMINE END AREA:

Sum of the fill between breaks times the distance between, for each section, minus the slope times the fill times the toe fill, for each side, equals the double area.

$$d_1(H_1 + H_2) + d_2(H_3 + H_2) + d_3(H_1 + H_4) + d_4(H_4 + H_5) - (\text{Front Toe Distance} - \frac{TW}{2})$$

$$(H_3) - (\text{Back Toe Distance} - \frac{TW}{2})(H_5) = \text{Double End Area.}$$

FILL:

5.1	5.0	9.2	15.0	15.5
21.3	12.2	0.0	10.0	37.0

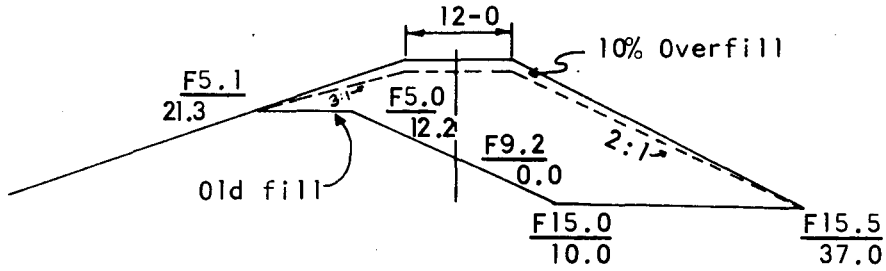
FILL WITH 10% ALLOWANCE FOR SETTLEMENT:

6.0	5.9	10.1	15.9	16.4
21.3	12.2	0.0	10.0	37.0

12.2 (5.9 + 10.1)	=	+ 195.20	
(21.3 - 12.2)(6.0 + 5.9)	=	+ 108.29	
10.0 (10.1 + 15.9)	=	+ 260.00	
(37.0 - 10.0)(15.9 + 16.4)	=	+ 872.10	
$(21.3 - \frac{12}{2})(6.0)$	=		- 91.8
$(37.0 - \frac{12}{2})(16.4)$	=		- 508.4
		+ 1435.52	- 600.2
		- 600.20	
Double End Area	=	+ 835.39	

METHOD 2

MULTIPLE SECTIONS BY COORDINATE METHOD



METHOD TO DETERMINE END AREAS:

Place a plus (+) sign by all the lower terms in the side toward the centerline and a negative (-) sign by all the lower terms in the side away from the centerline. Then by multiplying each upper term by the algebraic sum of the two adjacent lower terms, using the signs facing the upper term, the algebraic sum of these products is double the area of the cross section.

FILL:

5.1	5.0	9.2	15.0	15.5
21.3	12.2	0.0	10.0	37.0

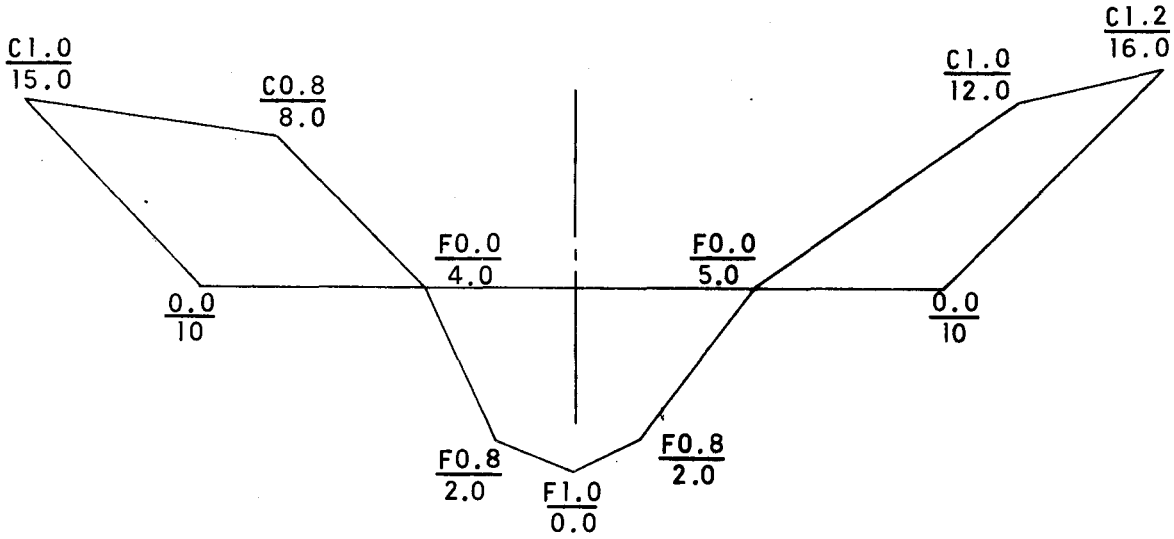
FILL WITH 10% ALLOWANCE FOR SETTLEMENT:

0.0	6.0	5.9	10.1	15.9	16.4	0.0
-6.0+	-21.3+	-12.2+	-0.0-	+10.0-	+37.0-	+6.0-

6.0 (+6.0 - 12.2)	=		- 37.20
5.9 (+21.3 - 0)	=	+ 125.67	
10.1 (+12.2 + 10.0)	=	+ 224.22	
15.9 (-0 + 37.0)	=	+ 588.30	
16.4 (-10.0 + 6.0)	=		- 65.60
		+ 938.19	-102.80
		- 102.80	
Double End Area	=	+ 835.39	

METHOD 2

MULTIPLE SECTION
BY COORDINATE METHOD
CUT & FILL SECTION



EXCAVATION:

0	1.0	0.8	0.0	0.0	0.0	1.0	1.2	0
-10.0+	-15.0+	-8.0+	-4.0+	0	+5.0-	+12.0-	+16.0-	+10.0-

1.0 (+10.0 - 8.0) = + 2.0
0.8 (+15.0 - 4.0) = + 8.8
1.0 (-5.0 + 16.0) = + 11.0
1.2 (-12.0 + 10.0) = -2.4
+ 21.8 -2.4
- 2.4
Double End Area = 19.4

FILL:

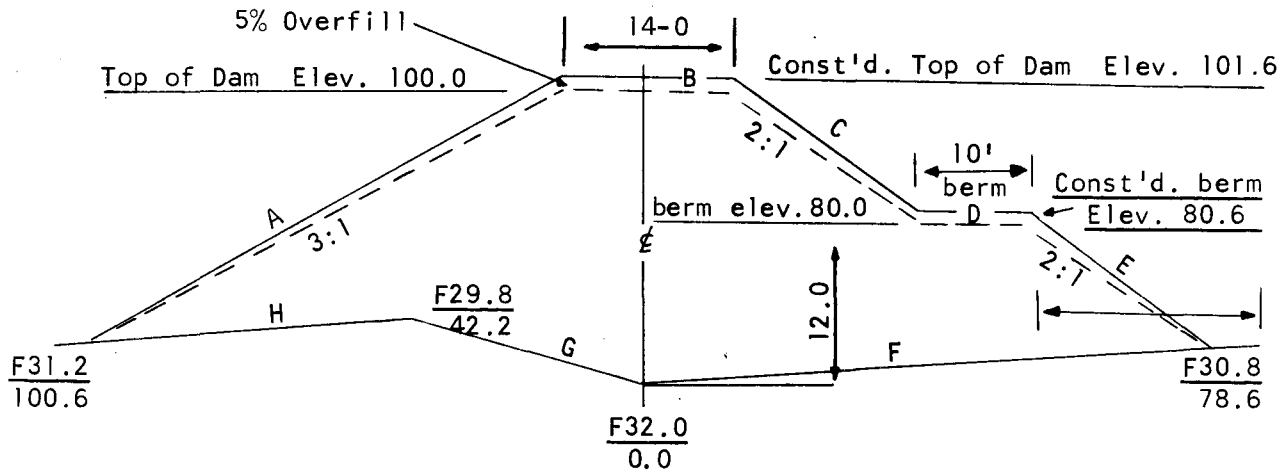
0.0	0.8	1.0	0.8	0.0
-4.0+	-2.0+	0	+2.0-	+5.0-

0.8 (+4.0 + 0) = + 3.2
1.0 (+2.0 + 2.0) = + 4.0
0.8 (0 + 5.0) = + 4.0

Double End Area = + 11.2

METHOD 3

MULTIPLE SECTIONS
BY DOUBLE MERIDIAN DISTANCE (D.M.D.)



℄ Overfill = (0.05)(32.0) = 1.6 feet.

Constructed Top of Dam Elevation = 100.0 + 1.6 = 101.6.

Berm Overfill = (0.05)(12.0) = 0.6 feet.

Constructed Top of Berm Elevation = 80.0 + 0.6 = 80.6.

Sometimes the berm must be constructed at a set elevation such as with principal spillways. In this case, the berm overfill would be zero.

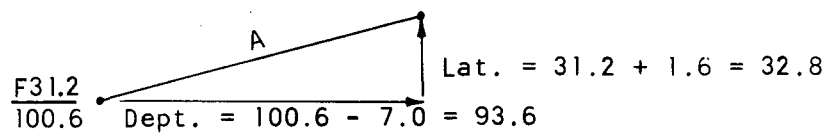
Method To Determine End Areas

Assign letters to each line. The height is referred to as latitude and the distance as departure. Start at the extreme left point of the cross section and proceed in a clockwise direction. Note each bounding line has an ascending (+) or decending (-) vertical latitude. It also has a right (+) or left (-) horizontal departure. The appropriate signs with latitude and departure for each line are entered in a table. The algebraic sum of both the latitude and departure must balance.

The D.M.D. value of the first line is equal to the departure of the first line. The D.M.D. value of each succeeding line is equal to the D.M.D. value of the preceding line plus the departure of the preceding line plus the departure of the line itself. The D.M.D. of the last line equals the departure of the last line but with the opposite sign. Note all addition is algebraic with respect to sign.

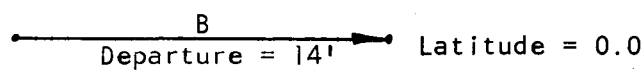
The Double Area is obtained by algebraic multiplication of each D.M.D. by its latitude and entered in its proper column according to its sign. Each Double Area column is added; the lesser total is subtracted from the larger total and the result is the Double Area of the figure.

Analysis of Line A:



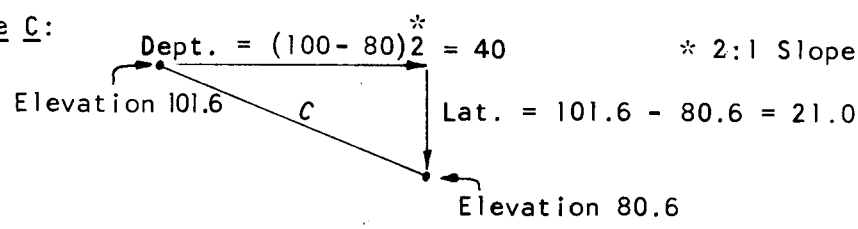
D.M.D. Value = +93.6.
Double Area = (+93.6)(+32.8) = +3070.08.

Analysis of Line B:



D.M.D. = 93.6 + 93.6 + 14.0 = +201.2.
Double Area = (+201.2)(0.0) = 0.0.

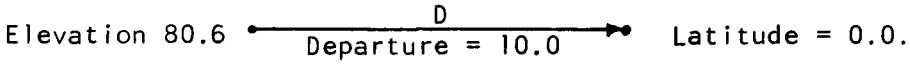
Analysis of Line C:



D.M.D. = 201.2 + 14.0 + 40 = +255.2.
Double Area = (255.2)(-21.0) = 5359.2.

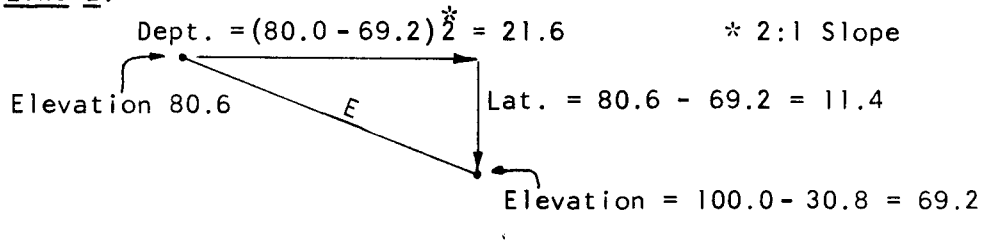
NOTE: Departures of side slope lines are based on design height and design slope. Departures do not change with overfill added, but latitudes will change.

Analysis of Line D:



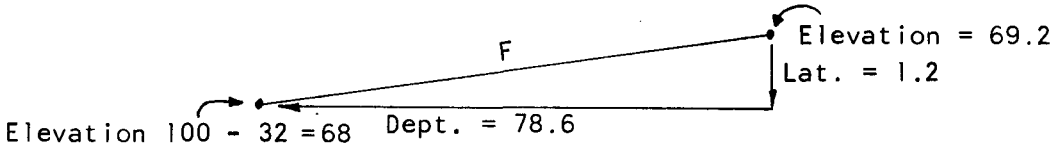
D.M.D. = +255.2 + 40.0 + 10.0 = +305.2.
Double Area = (+305.2)(0.0) = 0.0.

Analysis of Line E:



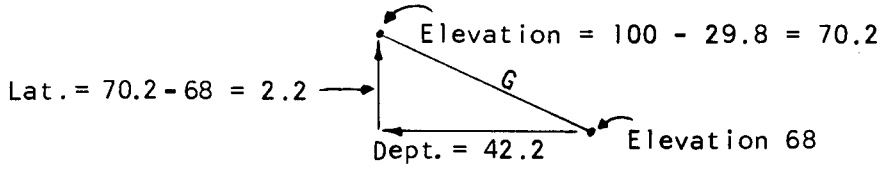
D.M.D. = +305.2 + 10 + 21.6 = +336.8.
Double Area = (+336.8)(-11.4) = -3839.52.

Analysis of Line F:



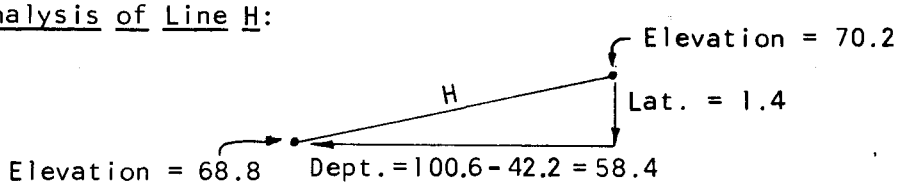
D.M.D. = +336.8 + 21.6 - 78.6 = +279.8.
Double Area = (279.8)(-1.2) = 335.76.

Analysis of Line G:



D.M.D. = 279.8 - 786 - 42.2 = +159.
Double Area = (159)(+2.2) = +349.8.

Analysis of Line H:



D.M.D. = 159 - 42.2 - 58.4 = +58.4.
Double Area = (58.4)(-1.4) = 81.76.

MULTIPLE SECTIONS
BY DOUBLE MERIDIAN DISTANCE (D.M.D.)

LINE	LATITUDE		DEPARTURE		D.M.D.	DOUBLE AREA	
	+	-	+	-		+	-
A	32.8		93.6		+ 93.6	3070.08	
B	0.0		14.0		+201.2	0.0	
C		21.0	40.0		+255.2		5359.20
D	0.0		10.0		+305.2	0.0	
E		11.4	21.6		+336.8		3839.52
F		1.2		78.6	+279.8		335.76
G	2.2			42.2	+159.0	349.8	
H		1.4		58.4	+ 58.4		81.76
TOTAL	35.0	35.0	179.2	179.2		+3419.88	-9616.24

+3419.88
Double Area = -6196.36

NOTE:

(1) Totals of Latitude must be equal.

(2) Totals of Departure must be equal.

(3) DMD of last line must be equal to departure of last line but with opposite sign.

(4) The negative total of the Double Area will always be greater than the positive total.