Terrace Channel Design and Evaluation

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Abstract

A procedure was developed to estimate the design elevations for a terrace channel bottom by varying channel grade and using a cut and fill method. Mathematical equations were derived to evaluate the cut and fill requirements for broad-base, grass-backslope, and narrow-base terrace cross-sections. Equations were also developed to estimate relative earth movement or efficiency for a straight blade bulldozer, a universal blade bulldozer, and scraper equipment. The equations were the basis of a computer program that was developed to design and evaluate the terrace channel profile and cross-section. The program was evaluated using terrace input data from northeast Nebraska.

Keywords. Terraces, Channel design.

Introduction

The development of a terrace design system becomes increasingly complex and time-consuming with the introduction of parallel terraces. Extensive calculations are required to compute cuts and fills, storage capacity, and earthwork quantities. In order to reduce the manual computation required, computer design aids have been developed (Forsythe and Pasley, 1969; Forsythe, 1972; Ryu, 1979). However, these design aids have two major drawbacks: 1) all the programs depend on the prior placement of the terrace before calculation can be performed; and 2) the time and labor required to enter data are high. To overcome these shortcomings, a complete terrace design program that locates conventional and parallel terraces, designs terrace channel profiles and cross-sections, and evaluates construction costs was developed (Ghidey, 1987; Sudduth and Gregory, 1982). The program performs the following functions: 1) data entry; 2) conventional and parallel terrace location; 3) channel profile selection; and 4) volume of soil computation.

Terraces are water control structures that must be designed to safely and economically collect and transport water to a designated outlet. To achieve this design, an optimum channel profile is determined considering both variation in grade and use of cuts and fills. In our system, channel elevations are adjusted according to the minimum and maximum allowable grades.

Larson (1969) developed mathematical equations that are useful for computing areas of cuts and fills at terrace cross-sections for broad-base and grass-backslope terrace designs. These equations are expressed in the basic dimensions of the terrace geometry and serve as a basis for balancing cut and fill volumes. In this article, Larson's equations are modified to estimate the depth, areas, and volume of cut and fill when the dimensions are changed to adjust for excess cut or fill – a typical condition when drainage is achieved for a parallel system. Additionally, equations to estimate cut and fill values for narrow-base terraces are derived.

To minimize the cost of earth movement along the channel, the construction machinery efficiency is evaluated. Equations are developed to determine the efficiency for a straight blade bulldozer, universal blade bulldozer, and a scraper.

The objective of this article is to discuss the various procedures followed and equations developed to design terrace channel profiles and cross-sections, and to evaluate cost of terrace construction.

Selection of Channel Grade

Alignment and farmability of many terrace systems can be improved if the channel grade is varied and cuts and fills are used. As earthwork is balanced by the cut and fill method, the terrace channel grade must be low enough to resist erosion but high enough to provide reasonable drainage. Recommendations for the limits are given by ASAE terrace design standard (ASAE, 1990). Suggested minimum grades are 0.2% for soils of low permeability and 0.0% for soils of high permeability. Maximum allowable grade can be computed using the following equation derived from the Manning equation (Beasley et al., 1984):

$$S = \frac{213.7\ V^{8/3}\left(\frac{Z^2+1}{Z}\right)^{2/3}}{(W_s\,L)^{2/3}} \tag{1}$$

where

S = the maximum allowable grade in percent
V = the maximum velocity (0.61 m/s)
Z = the channel sideslope ratio

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W_s = spacing between terraces
L = length along the terrace from the upper end

The channel elevations are adjusted to the minimum or maximum grades as required. If the channel elevation is below the minimum allowable elevation, it is adjusted according to the minimum allowable grade. If it is beyond the maximum allowable elevation, it is adjusted according to the maximum allowable grade. The cut/fill ratio is computed based on the cut and fill depths at each station. If the cut/fill ratio is too small, the channel is lowered to obtain less fill. If the cut/fill ratio is too large, the channel is raised to obtain less cut. The channel design procedure is discussed in detail by Ghidey (1987).

Terrace Cross-sections

Broad-base Terrace Cross-section

Figure 1a illustrates the cross section of a broad-base terrace with balanced cuts and fills. This type of terrace is normally built with constant ridge height, h. However, when cut and fill depths are varied to obtain parallel alignment, the cut and fill volume is no longer balanced at the given station. The horizontal distance, W, is constant and is equal to a whole multiple of the machinery width.

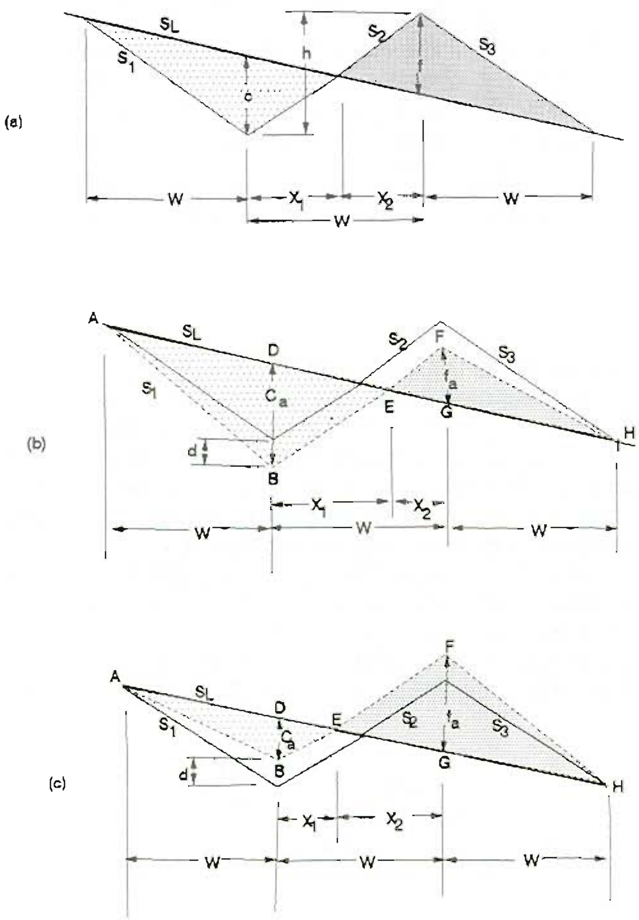

Figure 1–(a) Broad-base terrace cross section with balanced cut and fill.
(b) Broad-base terrace cross-section with excess cut.
(c) Broad-base terrace cross-section with excess fill.

Larson (1969) developed the following equations for broad-base terrace cross-section:

$$c + f = h + S_L W \quad (2)$$

$$S_1 = \frac{c}{W} + S_L \quad (3)$$

$$S_2 = \frac{h}{W} \quad (4)$$

$$S_3 = \frac{f}{W} + S_L \quad (5)$$

$$X_1 = \frac{W c}{c + f} \quad (6)$$

$$X_2 = \frac{W f}{c + f} \quad (7)$$

$$A_c = \frac{c W}{2}\left(1 + \frac{c}{c + f}\right) \quad (8)$$

$$A_f = \frac{f W}{2}\left(1 + \frac{c}{c + f}\right) \quad (9)$$

where

A_c = cross-sectional area of cut at each station
A_f = cross-sectional area of fill at each station
c = depth of cut
f = depth of fill
h = design depth of terrace channel
S_L = landslope
S_1 = cutslope
S_2 = frontslope
S_3 = backslope
W = horizontal distance equal to machine width
X_1 = horizontal distance from point of zero cut to channel centerline
X_2 = horizontal distance from point of zero cut to the ridge centerline

The terrace ridge height, h can be computed by (Beasley et al., 1984):

$$h = d_f + 0.15 \quad (10)$$

where d_f is the depth of flow and is given by:

$$d_f = 0.026 \frac{(Z^2 + 1)^{1/8}}{Z^{5/8}} (W_s L)^{3/8} \quad (11)$$

Equations 10 and 11 were developed for a broad-base cross-section where the channel sideslope ratio (Z) is the same for both the upslope and downslope portion of the channel. For grass-backslope and narrow-base cross-sections, the sideslope ratio will be slightly different compared to the broad-base. This change in sideslope ratio has only a minor effect on the calculated depth. Therefore, equations 10 and 11 are also used to calculate the ridge height for grassed-backslope and narrow-base cross-sections.

Broad-base Terrace with Balanced Cut and Fill

For a broad-base terrace with balanced cut and fill there will be enough borrow from the channel to build the ridge when the channel bottom is constructed to the desired elevation (fig. 1a). Depth of cut is equal to depth of fill at each station. Therefore:

$$c = f = \frac{1}{2}\left(h + S_L W\right) \qquad (12)$$

Also, area of cut is equal to area of fill at each station. Therefore:

$$A_c = A_f = \frac{c\,W}{2}\left(1 + \frac{c}{c + f}\right)$$

Substitution of f for c gives:

$$A_f = A_c = \frac{3}{4}\left(W\,c\right)$$

Substitution of the expression already developed for c gives:

$$A_f = A_c = \frac{3}{8}W\left(h + S_L W\right) \qquad (13)$$

Broad-base Terrace with Excess Cut

Figure 1b shows the cross-sectional area of a broad-base terrace with an excess cut required at the channel. The channel bottom is lowered by the amount d which causes the cut depth, c, to increase. In order to maintain a constant ridge height, h, the fill depth must decrease as cut depth increases. Due to this, cutslope and backslope are changed. Larson's equation must be modified to make this adjustment.

The adjusted depth of cut is:

$$c_a = c + d \qquad (14)$$

where d is the additional cut depth required to adjust the channel grade.

The adjusted depth of fill is:

$$f_a = f - d \qquad (15)$$

The values for S_1, S_3, X_1, and X_2 are computed using equations 3, 5, 6, and 7, respectively, with $c = c_a$ and $f = f_a$. The total area of cut is the sum of the areas of the triangles ABD and BDE (fig. 1b) and is calculated by:

$$A_c = \frac{1}{2}c_a\left(W + X_1\right) \qquad (16)$$

The total area of fill is the sum of the areas of triangles EFG and HFG and is calculated by:

$$A_f = \frac{1}{2}f_a\left(W + X_2\right) \qquad (17)$$

Broad-base Terrace with Excess Fill

This condition occurs when the channel bottom is raised to balance the cut and fill along the terrace channel (fig. 1c). Except for the depths of cut and fill, equations used for the broad-base terrace with excess cut can be used in the case of excess fill. The depth of cut is decreased by a value d, while the fill depth is increased by the same value. The adjusted depths of cut and fill are:

$$c_a = c - d \qquad (18)$$

$$f_a = f + d \qquad (19)$$

Grassed-backslope Terraces

A grassed-backslope terrace is constructed with a backslope which is too steep for row crops and is maintained in vegetative cover (fig. 2a). The frontslope (S_w) is made to fit the given farm equipment. The cutslope (S_c), where borrow is taken, generally has a slope of 0.001 to provide drainage and should be made at least as wide as the frontslope to make it farmable. For terraces with balanced cut and fill, the following equations were derived by Larson (1969):

$$f = h + S_L W \qquad (20)$$

$$X_3 = \frac{f}{S_b - S_L} \qquad (21)$$

$$X_4 = \frac{c}{S_b - S_L} \qquad (22)$$

$$A_f = \frac{f}{2}\left(W + \frac{f}{S_b - S_L}\right) \qquad (23)$$

$$A_c = c^2\left(\frac{1}{S_L - S_c} + \frac{1}{S_b - S_L}\right) \qquad (24)$$

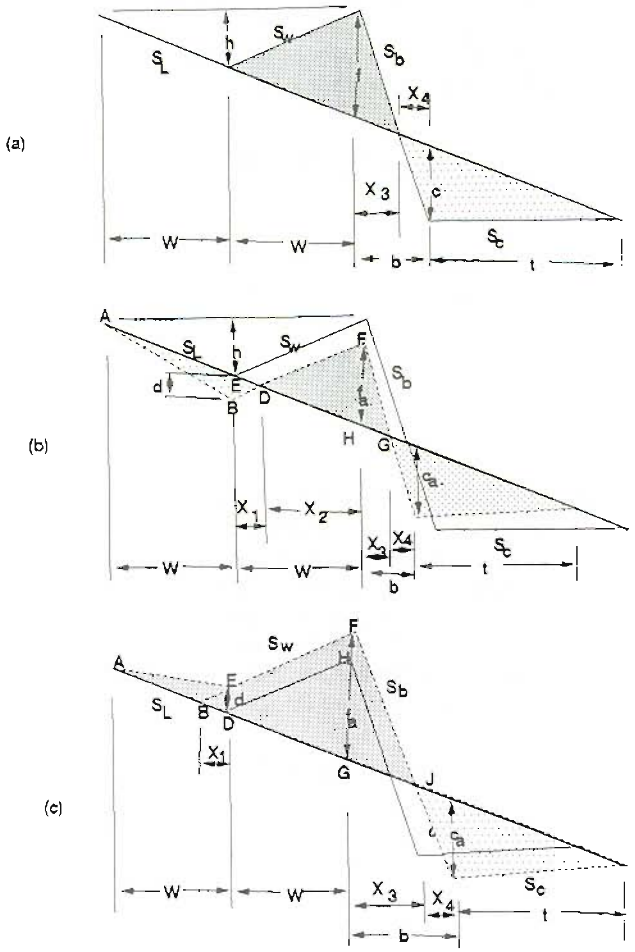

Figure 2–(a) Grassed-backslope terrace cross section with balanced cut and fill.
(b) Grassed-backslope terrace with excess cut.
(c) Grassed-backslope terrace with excess fill.

$$c = \sqrt{\frac{2A_c}{\frac{1}{S_L - S_c} + \frac{1}{S_b - S_L}}} \tag{25}$$

$$b = \frac{f + c}{S_b - S_L} \tag{26}$$

$$t = \frac{c}{S_L - S_c} \tag{27}$$

where

S_w = frontslope
S_c = cutslope
S_b = backslope
b = width of land out of production
t = width of cut area

Grassed-backslope Terrace with Excess Cut

As shown in figure 2b, the channel bottom must be cut to a specified depth to give the correct elevation. The earth removed can be used to fill the ridge. If the volume of cut is greater or equal to the volume of fill required, there is no need to have an additional cut from downslope. If the cut volume at the channel is greater than the required fill volume, then it can be moved along the channel, provided it is efficient to do so. The depth of fill is:

$$f_a = f - d \tag{28}$$

X_1 and X_2 are expressed by equations 6 and 7, respectively, letting $c = d$ and $f = f_a$.

The ridge fill area is the area of triangles DFH and FGH and is calculated by:

$$A_f = \frac{f_a}{2}(X_2 + X_3) \tag{29}$$

where X_3 has the same expression as equation 21 with $f = f_a$. The cut area along the channel is equal to the sum of the areas of triangles ABE and BED:

$$A_c = \frac{1}{2} d\left(W + X_1\right) \tag{30}$$

If the cut area along the channel is less than the required fill area, then the additional area of cut from downslope can be computed as:

$$A_{cd} = A_f - \frac{1}{2} d\left(W + X_1\right) \tag{31}$$

Once the area of cut downslope is determined, equations 25, 26, and 27 are used to compute the downslope cut depth, c_a, the width of land out of production, b, and the width of cut area, t, respectively.

Grassed-backslope Terrace with Excess Fill

Figure 2c illustrates a grassed-backslope terrace where the channel bottom is raised to a specified height to adjust to the proper elevation. In addition to the ridge fill requirement, extra soil is needed to fill the channel bottom. Since the ridge height is constant, fill depth must be raised. This changes the dimension of the cutslope section. The depth of fill is calculated as:

$$f_a = f + d \tag{32}$$

Triangles BFG and DHG are similar, therefore:

$$\frac{X_1 + W}{W} = \frac{f_a}{f}$$

Solving for X_1 gives:

$$X_1 = W\left(\frac{f_a}{f} - 1\right) \tag{33}$$

The area of ridge fill is the area of triangles BGF and JGF, and is calculated by:

$$A_{rf} = \frac{f_a}{2}\left((W + X_1) + \frac{f_a}{S_b - S_L}\right) \quad (34)$$

The area of channel fill is the area of triangle ABE, and is determined as:

$$A_{cf} = \frac{1}{2} d\,(W - X_1) \quad (35)$$

The total cut required must be equal to the fill needed on the ridge plus the excess fill needed on the channel:

$$A_c = A_{rf} + A_{cf} \quad (36)$$

Narrow-base Terraces

Narrow-base terraces (fig. 3a) have steep front and back-slopes which are kept in grass. The frontslope, S_w, is taken to be equal to the backslope. Because terrace slopes are not farmed, terrace width does not depend on the width of the machinery. Similar procedures followed in grassed-backslope terrace design can be used to derive the equations that apply for narrow-base terraces. The difference is, in a narrow-base terrace the front width, X, is not equal to a whole multiple of the machine width, W. The front width, X, can be computed by:

$$X = \frac{h}{S_w} \quad (37)$$

Narrow-based terraces with excess cut and excess fill are given in figures 3b and 3c, respectively. In all cases, the expressions given for f, A_f, A_c, c, b, t for the backslope-terrace cross sections are applicable to the narrow-base terraces with the front width W = X.

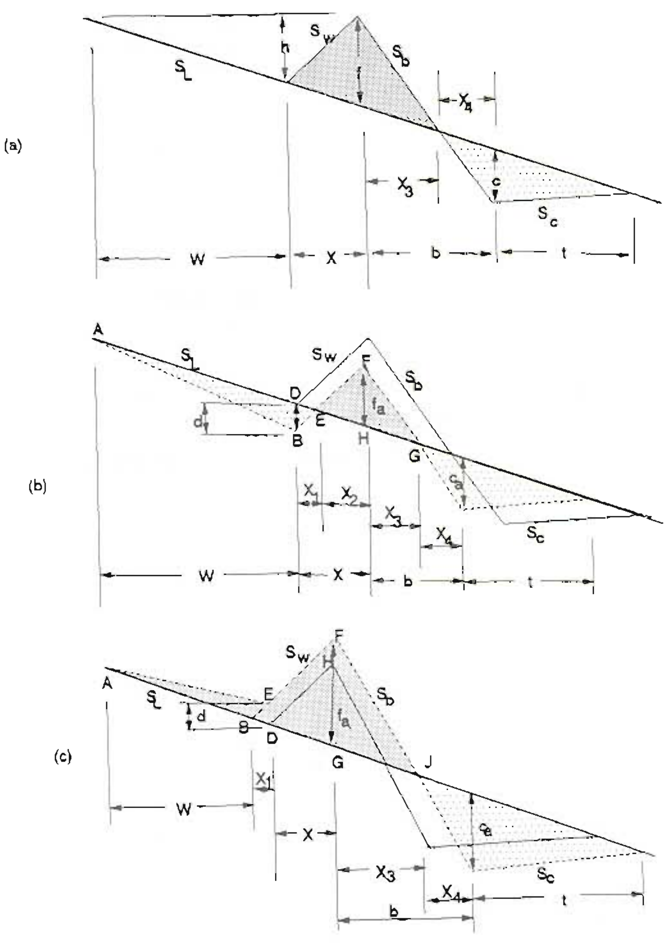

Figure 3–(a) Narrow-based terrace cross section with balanced cut and fill.
(b) Narrow-based terrace with excess cut.
(c) Narrow-based terrace with excess fill.

Terrace Channel Design Program

A computer program called MOTERR was written that designs the terrace channel profile and cross-section, and estimates the volume of soil needed to build a terrace using broad-base, grass-backslope, and narrow-base cross-sections. This program is one of several programs that work together to design the terrace system. For input, MOTERR requires the ground elevation of each point (station) on the terrace line, machine width, maximum velocity for soil conditions (0.61 m/s for most soils), landslope, and terrace spacing. Ground elevation data is provided by the terrace location program developed by Sudduth and Gregory (1982), and modified by Ghidey (1987).

The procedure followed to design the terrace channel is: (1) select a drain point, (2) adjust ground elevation according to minimum and maximum allowable grades, (3) compute cut and fill ratio, (4) if cut and fill ratio constraints are not satisfied, search for a point of maximum cut or fill (as required) and raise or lower elevations starting from this point. To select a drain point, the first and last points on the terrace line are compared, and the one with the lowest elevation is selected to be the drain point. Terraces with multiple drain points can be divided into subsegments, and each segment can be designed with the current program. The above procedure is repeated until the given cut and fill ratio constraints are satisfied, or the number of iterations exceeds the maximum allowed. If constraints are not satisfied, design is completed with unbalanced cuts and fills. Once the ground and channel elevations are determined, the design parameters and the volumes of cut and fill for a broad-base, grass-backslope, or narrow-base (as selected by the user) terrace cross-section are computed.

The procedure assumes that earth is moved from channel cut directly into ridge fill at each station. If the soil volume at channel cut is more than at ridge fill, then the excess cut is moved to the fills along the length of the terrace provided it is cost effective based on machine efficiency. To minimize the cost of earth movement along the channel, the construction machinery efficiency is evaluated.

Terrace systems vary in cost depending on spacing, length, type of cross-section, and topography. Cost for earth movement primarily depends on the volume of soil moved and the efficiency at which it is moved, which depends on the type of equipment used and the distance the soil is moved. Theoretically, efficiency is inversely proportional to the distance the soil is moved. Three equations were developed to estimate relative earth movement or efficiency from curves presented in the Caterpillar Performance Handbook (1983): one for a bulldozer with a straight blade, one for a bulldozer with a universal blade, and one for scraper equipment. The efficiency for a bulldozer with a straight blade is:

$$E = \frac{2W + 8.23}{D + 8.23} \tag{38}$$

The efficiency for a bulldozer with a universal blade is:

$$E = \frac{2W + 4.88}{D + 4.88} \tag{39}$$

The efficiency for a scraper is:

$$E = \frac{15.2 + 651.7\ e^{-12.3\,S}}{D + 651.7\ e^{-12.3\,S}} \tag{40}$$

where
- E = machine efficiency
- W = horizontal distance or machinery width defined for previous equations in meters
- D = dozing or scrapping distance in meters
- S = landslope in decimal

Whenever the efficiency of the soil movement fell below 50% of the efficiency to move soil from cutting in a channel to filling in a ridge at the same station, it was assumed that the contractor would cut or fill in the field instead of moving the soil great distances along the channel at low efficiencies. The actual amount of soil moved from cutting and filling was calculated based on the terrace cross-section equations.

To estimate cost of construction, an equivalent volume of soil moved was calculated. Equivalent volume was defined as the volume of soil moved at 100% efficiency and was evaluated with the following equation:

$$EV = \sum_{i=1}^{n} \frac{V_i}{E_i} \tag{41}$$

where
- EV = equivalent volume
- V_i = volume moved at each station
- E_i = efficiency at which local soil is moved
- n = number of stations along the terrace line

If cut volume was used in the fill volume, the equivalent volume calculation only counted the volume once. If excess cut occurred and it was dumped in the field as waste soil because of low efficiency in moving the soil to a fill location, the cut volume was added to the equivalent volume. Likewise, when extra fill was needed and it was not available at a reasonable (50% efficiency) distance, it was assumed that cuts would be made from the field area and this volume was added to the equivalent volume. The equivalent volume, therefore, is usually bigger than either the sum of all cuts or the sum of all fills but is less than the sum of all cuts and fills.

Program Evaluation

Terrace input data from northeast Nebraska (Wittmuss, 1985) were used to evaluate the performance and usability of MOTERR. A sample output for one of the terrace lines is presented in figures 4 and 5, and Tables 1 through 3.

To balance cuts and fills, a minimum channel grade of 0.1% was used, and the maximum channel grade was computed using equation 1 with a sideslope ratio of 10 and maximum velocity of 0.61 m/s. The cut and fill ratio used as a constraint was between 1.20 and 1.35. The maximum number of iterations allowed was 20, and the ground elevation was 7%.

Figure 4 illustrates the ground and channel elevations along the terrace line. According to Wittmuss's program (Nebraska terrace program) the initial proposed channel

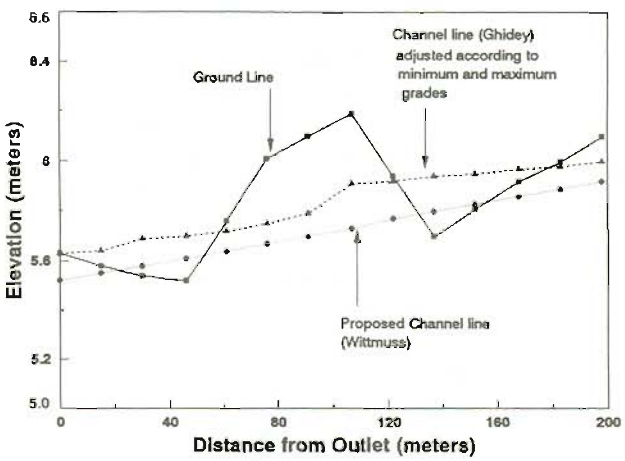

Figure 4–Initial lines for a broad-base terrace cross-section.

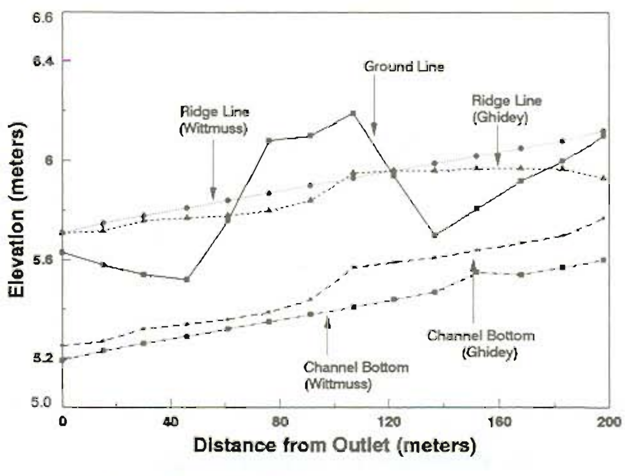

Figure 5–Initial lines for a broad-base terrace cross-section.

TABLE 1. Design of terrace channel profile and cross-section for broad-base terrace

Maximum allowable sideslope ratio = 10.0
Maximum allowable velocity = 0.61 m / s
Machine type = Bulldozer with a universal blade
Base width = 4.3 m
Cut-fill ratio = 1.28

Total volume of cut = 261.59 m^3
Total volume of fill = 232.28 m^3
Equivalent volume of soil moved = 362.50 m^3

Distance (m)	Ground Elev. (m)	Cut Depth (m)	Channel Elev. (m)	Ridge Ht. (m)	Ridge Elev. (m)
0	5.63	0.38	5.25	0.46	5.71
15	5.58	0.31	5.27	0.45	5.72
30	5.54	0.23	5.32	0.44	5.76
46	5.52	0.18	5.34	0.43	5.77
61	5.76	0.40	5.36	0.42	5.78
76	6.01	0.62	5.39	0.41	5.80
91	6.10	0.66	5.44	0.40	5.84
107	6.19	0.62	5.57	0.38	5.95
122	5.94	0.35	5.59	0.37	5.96
137	5.70	0.09	5.61	0.35	5.96
152	5.81	0.17	5.64	0.33	5.97
168	5.92	0.25	5.67	0.30	5.97
183	6.00	0.30	5.70	0.27	5.97
198	6.10	0.33	5.77	0.15	5.93

line is either specified by the user or selected by the program. For this terrace line, Wittmuss input the proposed channel line. Wittmuss's program first computes the volumes of cuts and fills and then evaluates the cut-fill ratio (volume ratio). If the desired cut-fill ratio is not achieved, the entire channel line is raised or lowered, as necessary, by an equal amount. MOTERR, on the other hand, adjusts channel bottom before computing cut and fill volumes. Cut-fill ratio is evaluated based on the depths of channel cuts and ridge fills. To satisfy the cut-fill ratio constraints, channel elevations are adjusted according to the minimum and maximum allowable grades, which reduces the volume of soil movement, and thus reduces the cost of the system. Furthermore, MOTERR considers the efficiency of soil movement with construction machinery and guards against the inefficient movement of soil over long distances. Wittmuss's program balances cuts and fills but does not consider the construction efficiency restriction.

The channel bottom and ridge lines obtained using both programs are shown in figure 5. MOTERR uses a uniform base width along the terrace line. Wittmuss's program, however, can use more than one base width. For this terrace line, Wittmuss used a base width of 4.3 m in all stations except one (8.6 m), and the total volume of channel cut and total volume of ridge fill were 374.0 and 278.0 m^3, respectively. MOTERR was run using 4.3 m base width, and the total volumes of channel cuts and ridge fills were 261.6 and 232.3 m^3, respectively (Table 1). Because of a better balance of cuts and fills, MOTERR computed less total volume of channel cut and ridge fill. MOTERR also minimizes soil movement along the terrace line by computing the equivalent volume (i.e., the volume of soil moved at 100% machinery efficiency). The equivalent volume of soil moved was 362.5 m^3 using a bulldozer with a universal blade. This volume can be used by the contractor to estimate the total cost of terrace construction.

MOTERR was also run for grass-backslope and narrow-base cross-sections. Tables 2 and 3 present the design parameters for grass-backslope and narrow-base terrace cross sections, respectively. Parameters evaluated include channel elevation, ridge height, ridge fill depth, downslope

TABLE 2. Design of terrace channel profile and cross-section for grass-backslope terrace

Landslope = 0.07	Machine width = 4.3 m
Frontslope = 0.11	Machine type = Bulldozer with a universal blade
Backslope = 0.50	Cut-fill ratio = 1.28
Cutslope = 0.01	Maximum land out of production = 3.57 m
Channel sideslope ratio = 10.00	

Total volume of downslope cut = 401.45 m^3
Total volume of channel cut = 46.30 m^3
Total volume of rideg fill = 422.78 m^3
Total volume of channel fill = 20.61 m^3
Equivalent volume of soil moved = 448.74 m^3

Distance (m)	Ground Elev. (m)	Channel Elev. (m)	Ridge Ht. (m)	Ridge Elev. (m)	Downslope Cut Depth (m)	Downslope Cut Width (m)	Land Out of Product (m)
0	5.63	5.63	0.46	6.09	0.49	8.18	2.91
15	5.58	5.64	0.45	6.10	0.54	9.02	3.15
30	5.54	5.69	0.44	6.13	0.60	10.01	3.46
46	5.52	5.70	0.43	6.13	0.62	10.39	3.57
61	5.76	5.72	0.42	6.14	0.43	7.23	2.58
76	6.01	5.75	0.41	6.16	0.08	1.28	1.21
91	6.10	5.79	0.40	6.19	0.00	0.00	0.90
107	6.19	5.91	0.38	6.29	0.00	0.00	0.92
122	5.94	5.92	0.37	6.29	0.41	6.83	2.46
137	5.70	5.94	0.35	6.28	0.63	10.56	3.53
152	5.81	5.95	0.33	6.28	0.56	9.27	3.08
168	5.92	5.97	0.30	6.27	0.47	7.81	2.60
183	6.00	5.98	0.27	6.25	0.39	6.48	2.18
198	6.10	6.00	0.15	6.15	0.22	3.63	1.32

TABLE 3. Design of terrace channel profile and cross-section for narrow-base terrace

Landslope = 0.07	Machine width = 4.3 m
Frontslope = 0.50	Machine type = Bulldozer with a universal blade
Backslope = 0.50	Cut-fill ratio = 1.28
Cutslope = 0.01	Maximum land out of production = 2.42 m
Channel sideslope ratio = 10.00	

Total volume of downslope cut = 106.06 m^3
Total volume of channel cut = 9.34m^3
Total volume of rideg fill = 88.13 m^3
Total volume of channel fill = 24.75 m^3
Equivalent volume of soil moved = 117.16 m^3

Distance (m)	Ground Elev. (m)	Channel Elev. (m)	Ridge Ht. (m)	Ridge Elev. (m)	Downslope Cut Depth (m)	Downslope Cut Width (m)	Land Out of Product (m)
0	5.63	5.63	0.46	6.09	0.24	4.05	1.79
15	5.58	5.64	0.45	6.10	0.29	4.88	2.03
30	5.54	5.69	0.44	6.13	0.35	5.80	2.32
46	5.52	5.70	0.43	6.13	0.37	6.13	2.42
61	5.76	5.72	0.42	6.14	0.17	2.88	1.42
76	6.01	5.75	0.41	6.16	0.00	0.00	0.47
91	6.10	5.79	0.40	6.19	0.00	0.00	0.33
107	6.19	5.91	0.38	6.29	0.00	0.00	0.35
122	5.94	5.92	0.37	6.29	0.14	2.32	1.25
137	5.70	5.94	0.35	6.28	0.37	6.12	2.33
152	5.81	5.95	0.33	6.28	0.30	4.93	1.89
168	5.92	5.97	0.30	6.27	0.21	3.49	1.41
183	6.00	5.98	0.27	6.25	0.12	2.09	0.96
198	6.10	6.00	0.15	6.15	0.00	0.00	0.17

cut depth, downslope cut width, and land out of production at each station. Total volumes of downslope cut, channel cut, ridge fill, channel fill, and equivalent volume of soil moved along the channel are also computed.

SUMMARY

A procedure was developed to estimate the design elevations for a terrace channel bottom by varying channel grade and using the cut and fill method. Based on Larson's (1969) study, mathematical equations were developed to estimate terrace design parameters including cut depth, fill depth, ridge height, cut volume, and fill volume for broad-base, grass-backslope, and narrow-base terrace cross-sections. Relationships were also developed to estimate the machinery efficiency of earth movement along the channel for a straight blade bulldozer, universal blade bulldozer, and scraper.

A computer program called MOTERR was developed that designs the terrace channel profile and cross-section, and estimates the volume of soil needed to build a terrace. MOTERR incorporates the procedures and mathematical equations described in this article. MOTERR was evaluated using terrace input data from northeast Nebraska. As compared to the Nebraska terrace design system, MOTERR required fewer input data, provided better balanced cut to fill ratio, and required less volumes of channel cut and ridge fill. In addition, MOTERR evaluated construction machine efficiency of earth movement along the channel and estimated the equivalent volume of soil moved. This volume provides a contractor with the best estimate of the construction cost.

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