# 테라스 築造費用을 推定하기 위한 모터 스크레이퍼 作業의 모델링

# Modeling Scraper Operations for Estimating Terrace Construction Costs

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## 摘 要

現在 農用테라스(Terrace) 築造費用의 推定은 單位 테라스長이나 移動土量의 單價에 根據하고 있다. 그러나, 近來 美國의 옥수수地帶(corn belt)에서 널리 利用되고 있는 平行型 테라스의 경우 各地點마다 盛土 및 切土量이 다르기 때문에 이들 方法은 適合하지 않다. 이들 테라스의 경우 테라스長을 따라 土量의 移動이 不可避하므로 車輪型 自積式 스크레이퍼(Scraper)가 테라스 築造에 널리 使用되고 있다.

本研究의 目的은 테라스 築造機械의 運行距離에 根據하여 테라스 築造時의 土工費用을 推定하기 위한 새로운 方法을 開發하는데 있었다. 테라스 築造時 土工作業은 全的으로 스크레이퍼에 의해서, 그리고 테라스 傾保長의 마무리 作業은 모터 그레이더(motor grader)에 의하여 遂行되는 것으로 假定하였다. 이들 機械의 細部的인 運行動作은 테라스 各地點에서의 切土와 盛土量 및 이들 土量의 處理를 디지탈 콤퓨터(digital computer)를 利用하므로서 計算할 수 있었다. 또한 테라스 築造에 所要되는 土量은 全的으로 테라스 水路部分에서 切取하는 것으로 假定하였다. (即, 테라스 全長의 總切土量과 總盛土量은 같음)

研究結果 다음과 같은 結論을 얻었다.

1. 盛土 및 切土量이 均衡된 테라스에 있어서는 스크레이퍼의 運行距離에 根據하여 土工費用을 推定할 수 있는 方法의 開發이 可能하다.
2. 스크레이퍼의 運行區間, 回數 및 土工費用을 決定하기 위해서는 콤퓨터方法을 利用하는 것이 必要하다.
3. 새로운 콤퓨터 모델은 例示의 테라스에 適用한 結果 테라스 土工費用을 推定하는데 適合함을 보여 주었다.
4. 이 方法은 테라스 築造에 있어서 效率的인 스크레이퍼의 運用에 指針이 될 수 있다.

## INTRODUCTION

Conventional methods for estimating the cost of earthmoving in farm terrace construction have been based on either the volume of earth moved or the linear length of the terrace (Wittmuss, 1971). Such estimations are not appropriate for most parallel terraces because they require varying amounts of cut-and-fill volumes from station to station along the terrace. A movement of soil from station to station along the terrace is inevitable, so self-loading wheel scrapers are generally used for such construction. Methods for balancing the cut-and-fill volumes and for minimizing the required machine operat-

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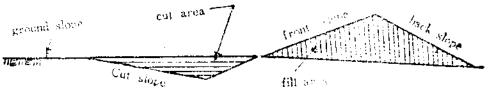
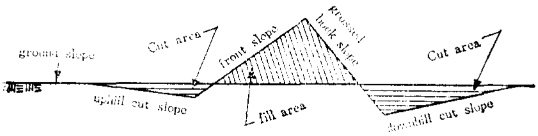
ions are needed to reduce terrace-construction costs.

The type of terrace has an effect on the procedure for its construction. As pictured in Figure 1, broad-base terraces have shallow slopes to allow farming over the terrace and are appropriate for fields with moderate slopes. Grassed-backslope terraces are used for fields with slopes of 6 percent and more. These terraces have a steep back or downhill slope, generally 2 : 1, which is maintained in grass the year around. Parallel terraces permit efficient operation of rowcrop machines by providing constant-width subfields. In most soils, terraces require a graded channel to permit low-velocity runoff either into an underground tile outlet or into a surface waterway. Any model of construction costs must accomodate these different types of terrace designs.



(a) broad-base terrace



(b) grassed-backslope terrace

**Fig 1. Two common types of farm terraces.**

This paper abstracts the construction-machinery modeling portions from a larger research effort reported by Ryu (1979). As a part of the optimization of production of row crops on sloping land, it was necessary to predict construciion-machinery operation costs for the various types of terraces so that evaluations of proposed system could then be made. These evaluations included the cost of soil erosion and crop-production machinery operations as well as the cost of terrace construction.

The objective of this paper is to report a method for estimating the earthmoving costs of terrace construction based on the travel of the construction machinery. The terraces were assumed to be built with a self-loading scraper and with a motor grader that was used only for finish work on the terrace slopes. This approach requires a description of the most efficient movements of the machinery as they are used to build a terrace. The detailed movement of the machinery can be calculated by analyzing the amounts and required dispositions of the cut-and-fill volumes using a digital computer. It is assumed that the terraces are built only with the soil taken from the terrace channel; that is, the volume of earth cut and fill must balance over the entire terrace. The computer schedules the amount of scraper and grader travel required to completely build the terrace.

## DEVELOPMENT OF THE MODEL

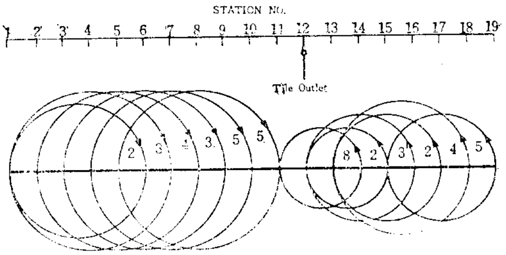
A model for estimating earthmoving costs was developed based on the required movements of the scraper. Because any transport travel time is wasteful, the best design minimizes transport distances and produces a least cost. Optimum scraper travel consists only of loading, turning, and unloading a completely filled bowl. A calculation of scraper travel should be based both on the volume of soil movement and on the number of cuts required. Total travel is determined by the larger of the two requirements.

Scraper travel based on volume moved

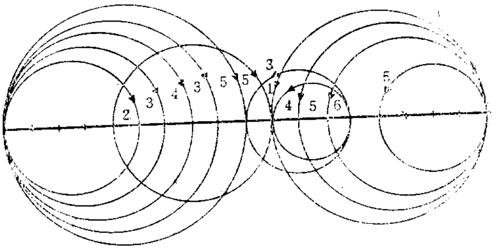
depends on the location of the cuts and the disposition of the fills at each station. The locations are established by the design of the proposed terrace. The model requires that the **minimum interval** be the distance during loading that the scraper requires to fill its bowl capacity. Assuming that enough soil needs to be cut, the minimum travel required is determined by the cut depth, the cut width, and the scraper's bowl capacity.

It is common to move soil laterally from both ends of the terrace toward the middle. In such cases the direction of lateral soil movement and the associated direction of loaded scraper travel changes somewhere in the middle. The station at which the travel direction changes is defined as the **dividing point**, which is theoretically the station where the accumulated volume of excess cut, defined as cut volume minus fill volume, becomes zero. The sign of the accumulated volume of excess cut at the station on either side of the dividing point may be either positive or negative. Because a dividing point usually occurs somewhere between the two stations, the dividing point is approximated as the station prior to the one where the sign of accumulated volume of excess cut changes.

A schematic representation of the scraper-movement patterns, or cycles, is given in Figure 2a. The cycles originate at the left end of the terrace as viewed from downslope. The first cycle proceeds in a clockwise direction from Station 1; soil is cut and loaded during the upper part of the circle. The scraper turns across the terrace at Station 6 and, in returning to Station 1, unloads during the lower part of the circle. As pictured, two cycles are required through Stations 1 and 6 before the scraper moves on to Station 2 to begin the three cycles required through Stations 2 and 7. Station 11 is a dividing point for this terrace as the cycle rotation reverses.



(a) original-based on volume moved



(b) modified-accommodates limited scraper cut

**Fig. 2. Scraper cycle diagrams.**

The logic associated with the details of scraper movement has been designed into a computer program. The rules for establishing starting points, turning points, cycles, and number of trips are as follows:

Rule I:

When the accumlated volume of excess cut is positive, the direction of travel around the cycle is established as clockise.

1. The first station from the left or from a dividing point is a starting point for the current scraper cycle.
2. A turning point is where the scraper ceases loading or cutting and starts back along the terrace to unload. The travel interval between the starting and turning points must satisfy the

following conditions:

   a. The interval must exceed the minimum interval unless a dividing doint is met.
   b. The soil volume to be filled for the interval must be at least the amount of the scraper's bowl capacity.
   c. The soil volume to be cut over the interval must be more than that for the fill.

3. After the turning point is found, the number of trips required for the cycle is determined by dividing the volume to be filled the scraper capacity and then rounding down to an integer number. Any fractional amount of a trip is left over for the next cycle.
4. The starting point for the next set of scraper cycles is determined as follows:
   a. Unless the accumulated cut volume at the station succeeding the current starting point is less than the accumulated amount of soil removed by the scraper thus far, the starting point remains the same.
   b. If the accumulated soil volume removed by the scraper exceeds the accumulated cut volume at the station succeeding the current starting point, the starting point of the next cycle moves to the station preceding the one where the accumulated cut volume exceeds the accumulated soil volume removed by the scraper.
5. The above steps,2 through 4, are repeated until a dividing point or the last station is met.

Rule II:

When the accumulated volume of excess cut is negative or the direction of cycle is counterclockwise:

1. The first station or a dividing point becomes the turning point of the cycle to be determined.
2. The starting point is determined as satisfying the following conditions:
   a. The interval between the turning point and the starting point must exceed the minimum interval unless a dividing point is met.
   b. The soil volume to be cut for the interval of the cycle must be at least the amount of the scraper's bowl capacity.
   c. The soil volume to be filled for the interval must be more than the volume to be cut.
3. After the starting point is found, the number of trips required for the cycle is determined by dividing the soil volume to be cut by the scraper capacity and by rounding down to an integer number. Any fractional amount of a trip is left over for the next cycle.
4. The turning point for the next cycle is determined as follows:
   a. Unless the accumulated fill volume at the station succeeding the current turning point is less than the accumulated amount of soil removed by the scraper thus far, the turning point remains the same.
   b. If the accumulated amount of soil removed by the scraper exceeds the accumulated fill volume at the station succeeding the current turning point, of the next cycle moves to the station preceding the one where the accumulated fill volume exceeds the accumulated amount of soil removed by the scraper thus far.
5. The above steps, 2 through 4, are rep-

eatedil until a dividing point or the last station is met. After determining all the scraper cycles using the above rules, the number of scraper passes at each station is determined by the relationship of the cycles and the stations.

The previous scraper cycles are based only on soil volume moved regardless of the shapes of the cross-sectional areas of cut. The scraper cycle diagram shown in Figure 2a must be revised to accomodate reality in shaping the terrace channel. The number of scraper passes actually required at each station is determined by the geomtrical shape of the cross-sectional areas of cut, as shown in Figure 3. The required passes depend on the maximum depth of cut and the width of cut per scraper pass. The following mathematical expressions relate to Figure 3 and are required to predict the actual passes of the scraper:

$$N_t=\sum_{i}^{n}=N_i$$

$$n=C\frac{\cos(\tan^{-1}S_g)}{C_s}$$

$$N_i=\frac{D_i}{W_s}$$

$$D_i=\frac{W_1}{\cos(\tan^{-1}S_g)}+\frac{X}{\cos(\tan^{-1}S_g)}$$

$$-C_s(\frac{1}{\tan(\tan^{-1}S_1-\tan^{-1}S_g)}$$

$$+\frac{1}{\tan(\tan^{-1}S_2+\tan^{-1}S_g}) \ (i-1)$$

Where $i$=the index number for the cut layers

$N_t$=total number of scraper passes

$n$=number of layers of scraper cuts

$N_i$=number of scraper passes for each layer

$D_t$=width of each layer

$C_s$=depth of the layer and the maximum scraper cut per pass

$W_s$=width of scraper cut

$X=C\ W_2/(C+f)$

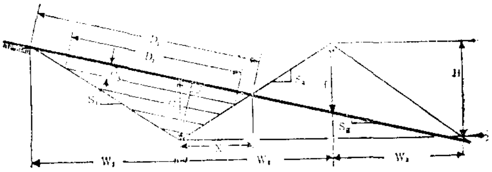


**Fig. 3. Location and dimensions of scraper cuts on a broad-base terrace.**

The number of scraper passes determined by the geometrical shapes of cuts is compared with the number based on soil volume. Those stations that require fewer scraper passes for volume than they do for geometry need extra scraper passes. The extra travel of the scraper is determined by multiplying the difference in passes at a station by the distance between the station having the extra passes and its adjacent station in the direction of scraper cycle.

Total travel distance of the scraper is then determined by the number of trips and the interval for each cycle and by adding the extra travel distance. Adding the extra travel distance means in reality that the scraper moves back beyond the starting point of the scraper cycle in order to clear the previous unfinished cuts.

The cost of earthmoving is then determined by the following expression:

$$COST_1=(\sum_{i=1}^{n}\frac{1}{1,000}\times N_i\times D_i)$$

$$\times(\frac{1}{S_c}+\frac{1}{S_f})+\sum_{i=1}^{n}\frac{T}{60}\times N_i)\frac{C_h}{E_f}$$

where $COST_1$=earthmovingcost by scraper, S

$n$=total number of cycles

$N_i$=number of trips for each cycle

$D_i$=cycle interval for each cycle, m

$S_c$ = loading (cutting) speed, km/h

$S_f$ = unloading (filling) speed, km/h

$T$ = turning time per trip, min

$C_h$ = hourly cost of scraper use, \$/h

$E_f$ = work efficiency, decimal

The cost of finish work on the terrace slopes is based on the travel of the motor grader. Its travel distance is determined by the base width of the terrace slopes, the width of the grader blade, and the length of the terraces. The cost of finish work is then determined from the hours and the hourly cost of using the motor grader as follows:

$$COST_2 = \left(\frac{D_{gr}}{S_{gr}}\right) C_{gr}$$

where $COST_2$ = cost of finish work by motor grader, \$

$D_{gr}$ = total travel distance of motor grader on terrace slopes, km

$S_{gr}$ = working speed of motor grader, km/h

$C_{gr}$ = hourly cost of motor grader, \$/h

## COMPUTER PROGRAMMING

A computer program incorporating the logical and mathematical models developed in the analysis of the problem was written in FORTRAN language. The program aids a terrace designer in estimating the earthmoving cost for constructing terraces having balanced earthwork.

The computer determines the starting points, turning points, and number of passes of each cycle to find total scraper travel. It also finds the travel distance of the motor grader. It then estimates the cost of terrace construction based on the travel distance of the scraper and motor grader.

The following input data are required for the program.

1. Type of terrace (broad-base or grassed-backslope)
2. Station number and number of stations
3. Distance of each station from Station 1
4. Base widths of terrace slopes at each station
5. Ground elevation at each station
6. Channel elevation at each station
7. Ridge elevation at each station
8. Ground slope at each station
9. Soil-shrinkage factor

## RESULTS AND DISCUSSION

The computer program was tested using typical input data. Table 1 shows the dimensions of terrace cross sections for a typical terrace with an underground tile outlet. Figure 4 shows the distirbution of cuts and fills for the entire terrace. It was assumed that the scraper had a bowl capacity of 6.747m$^3$ with a working cut depth of 6.25cm and a blade width of 2.4m, thereby resulting in the minimum interval of 45m$\left(\frac{6.747}{2.4 \times 0.0625}\right)$

**Table 1. Dimensions of Broad-base Terrace Cross Sections for an Example Terrace, m***

| Station | Cut depth ($C$) | Fill depth ($f$) | Ridge height ($H$) | Cut slope base ($W_1$) | Front slope base ($W_2$) | Back slope base ($W_3$) |
|---|---|---|---|---|---|---|
| 1 | 0.46 | 0.01 | 0.30 | 4.20 | 4.20 | 4.20 |
| 2 | 0.46 | 0.01 | 0.30 | 4.20 | 4.20 | 4.20 |
| 3 | 0.46 | 0.01 | 0.30 | 4.20 | 4.20 | 4.20 |
| 4 | 0.46 | 0.01 | 0.30 | 4.20 | 4.20 | 4.20 |
| 5 | 0.34 | 0.17 | 0.34 | 4.20 | 4.20 | 4.2 |
| 6 | 0.34 | 0.35 | 0.52 | 4.20 | 4.20 | 4.20 |
| 7 | 0.31 | 0.41 | 0.55 | 4.20 | 4.20 | 4.20 |
| 8 | 0.32 | 0.43 | 0.58 | 4.20 | 4.20 | 4.20 |
| 9 | 0.31 | 0.50 | 0.64 | 4.20 | 4.20 | 4.20 |
| 10 | 0.28 | 0.53 | 0.64 | 4.20 | 4.20 | 4.20 |
| 11 | 0.26 | 0.58 | 0.67 | 4.20 | 4.20 | 4.56 |
| 12 | 0.13 | 0.68 | 0.64 | 4.20 | 4.20 | 5.35 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | 0.34 | 0.44 | 0.61 | 4.20 | 4.20 | 4.20 |
| 14 | 0.34 | 0.41 | 0.58 | 4.20 | 4.20 | 4.20 |
| 15 | 0.34 | 0.38 | 0.55 | 4.20 | 4.20 | 4.20 |
| 16 | 0.34 | 0.32 | 0.49 | 4.20 | 4.20 | 4.20 |
| 17 | 0.46 | 0.14 | 0.43 | 4.20 | 4.20 | 4.20 |
| 18 | 0.46 | 0.01 | 0.30 | 4.20 | 4.20 | 4.20 |
| 19 | 0.46 | 0.01 | 0.30 | 4.20 | 4.20 | 4.20 |

* Ground slopes at each station are 4 percent or 0.04

The scraper for the example terrace are listed in Table 2. These values may be validated by hand calculations using the rules prescribed in the model-development section.

Table 3. shows the computer output for soil volumes moved at each station and the number of scraper passes at each station. The numerals in the "Passes (vol)" column refer to the minimum passes required to provide enough volume (see Figure 2a). The numerals in the "Passes (geo)" column show the number required to satisfy the cut geometry (see Figure 2b).

Table 4 compares the number of scraper passes at each station. Column 5 indicates the minimum number of passes required considering both volume moved and the geometry of cut. Column 6 shows the number of scraper passes obtained from the modified cycle diagram in Figure 2b. Column 7 shows the difference in the number of scraper

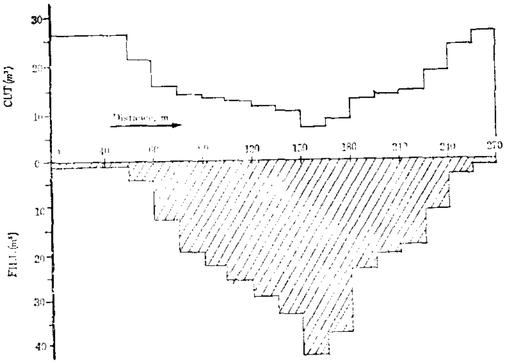


Fig. 4. Distribution of cuts and fills for an example terrace.

Table 2. Scraper Cycles

| Cycle number | Starting point | Turning point | Cycle interval | Cycle rotation | Soil volume | Number of trips |
|---|---|---|---|---|---|---|
| 1 | 1 | 6 | 75 | cw | 17.98 | 2 |
| 2 | 1 | 7 | 90 | cw | 24.85 | 3 |
| 3 | 2 | 8 | 90 | cw | 27.57 | 4 |
| 4 | 3 | 9 | 90 | cw | 26.44 | 3 |
| 5 | 4 | 10 | 90 | cw | 35.56 | 5 |
| 6 | 5 | 11 | 90 | cw | 35.06 | 5 |
| 7 | 14 | 11 | 45 | ccw | 39.18 | 8 |
| 8 | 15 | 12 | 45 | ccw | 19.55 | 2 |
| 9 | 16 | 12 | 60 | ccw | 20.71 | 3 |
| 10 | 17 | 13 | 60 | ccw | 19.63 | 2 |
| 11 | 18 | 13 | 75 | ccw | 31.01 | 4 |
| 12 | 19 | 15 | 60 | ccw | 30.31 | 5 |

**Table 3. Earthwork Volume and Scraper Passes (Trial 1, Terrace No. 1)**

| Station number | Distance (m) | Area cut ($m^2$) | Area fill ($m^2$) | Volume cut ($m^3$) | Volume fill ($m^3$) | Cumul. cut ($m^3$) | Cumul. fill ($m^3$) | Excess cut ($m^3$) | Passes (vol) | Passes (geo) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0. 00 | 1. 75 | 0. 02 | 0. 00 | 0. 00 | 0. 00 | 0. 00 | 0. 00 | 5 | 17 |
| 2 | 15. 00 | 1. 75 | 0. 02 | 26. 29 | 0. 28 | 26. 29 | 0. 28 | 26. 01 | 9 | 17 |
| 3 | 30. 00 | 1. 75 | 0. 02 | 26. 29 | 0. 28 | 52. 58 | 0. 57 | 52. 02 | 12 | 17 |
| 4 | 45. 00 | 1. 75 | 0. 02 | 26. 29 | 0. 28 | 78. 88 | 0. 85 | 78. 03 | 17 | 17 |
| 5 | 60. 00 | 1. 09 | 0. 52 | 21. 33 | 4 ·05 | 100. 20 | 4. 90 | 95. 30 | 22 | 11 |
| 6 | 75. 00 | 0. 98 | 1. 22 | 15. 50 | 1. 308 | 115. 70 | 17. 98 | 97. 73 | 20 | 11 |
| 7 | 90. 00 | 0. 85 | 1. 49 | 13. 72 | 20. 36 | 129. 42 | 38. 34 | 91. 08 | 17 | 9 |
| 8 | 105. 00 | 0. 88 | 1. 57 | 12. 98 | 22. 97 | 142. 41 | 61. 31 | 81. 10 | 13 | 9 |
| 9 | 120. 00 | 0. 82 | 1. 88 | 12. 77 | 25. 86 | 155. 17 | 87. 17 | 68. 01 | 10 | 9 |
| 10 | 135. 00 | 0. 72 | 2. 04 | 11. 62 | 29. 36 | 166. 79 | 116. 52 | 50. 27 | 5 | 8 |
| 11 | 150. 00 | 0. 65 | 2. 39 | 10. 34 | 33. 24 | 177. 14 | 149. 76 | 27. 37 | 0 | 8 |
| 12 | 165. 00 | 0. 29 | 3. 34 | 7. 09 | 43. 03 | 184 ·22 | 192. 79 | −8. 57 | 8 | 3 |
| 13 | 80. 00 | 0. 94 | 1. 60 | 9. 22 | 37. 05 | 193. 44 | 229. 84 | −36. 40 | 13 | 10 |
| 14 | 195. 00 | 0. 95 | 1. 47 | 14. 17 | 23. 01 | 207. 61 | 252. 85 | −45. 24 | 19 | 10 |
| 15 | 210. 00 | 0. 96 | 1. 35 | 14. 35 | 21. 13 | 221. 96 | 273. 98 | −52. 02 | 11 | 11 |
| 16 | 225. 00 | 0. 99 | 1. 10 | 14. 65 | 18. 35 | 236. 61 | 292. 32 | −55. 71 | 14 | 11 |
| 17 | 240. 00 | 1. 56 | 0. 40 | 19. 16 | 11. 22 | 255. 77 | 303. 55 | −47. 77 | 11 | 15 |
| 18 | 255. 00 | 1. 75 | 0. 02 | 24. 88 | 3. 11 | 280. 65 | 306. 66 | −26. 01 | 9 | 17 |
| 19 | 270. 00 | 1. 75 | 0. 02 | 26. 29 | 0. 28 | 306. 94 | 306. 94 | 0. 00 | 5 | 17 |

**Table 4. Comparison of the Number of Scraper Passes at Each Station**

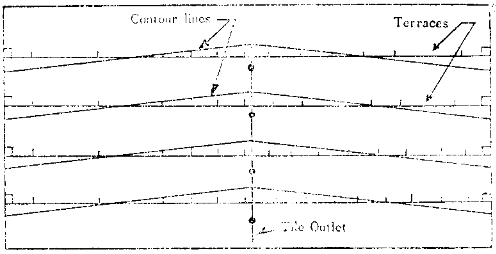
| 1 Station | 2 Passes* (vol) | 3 Passes (geo)$^+$ | 4 Extra passes (positive differences) (column 3 minus column 2) | 5 Column 2 plus column 4 | 6 Passes (mod)** | 7 Extra travel (column 6 minus column 5) |
|---|---|---|---|---|---|---|
| 1 | 5 | 17 | 12 | 17 | 17 | 0 |
| 2 | 9 | 17 | 8 | 17 | 17 | 0 |
| 3 | 12 | 17 | 5 | 17 | 17 | 0 |
| 4 | 17 | 17 | — | 17 | 17 | 0 |
| 5 | 22 | 11 | — | 2z | 22 | 0 |
| 6 | 20 | 11 | — | 20 | 20 | 0 |
| 7 | 17 | 9 | — | 17 | 17 | 0 |
| 8 | 13 | 9 | — | 13 | 1 | 3 |
| 9 | 10 | 9 | — | 10 | 10 | 0 |
| 10 | 5 | 8 | 3 | 8 | 8 | 0 |
| 11 | 5-8 | 8 | — | 8 | 8 | 0 |
| 12 | 8 | 3 | — | 8 | 8 | 0 |
| 13 | 13 | 10 | — | 13 | 13 | 0 |
| 14 | 19 | 10 | — | 19 | 19 | 0 |
| 14 | 11 | 11 | — | 11 | 12 | 1 |
| 16 | 14 | 11 | — | 14 | 17 | 3 |
| 17 | 11 | 15 | 4 | 15 | 17 | 2 |
| 18 | 9 | 17 | 8 | 17 | 17 | 0 |
| 19 | 5 | 17 | 12 | 17 | 17 | 0 |

*Obtained from the cycle diagram in Figure 2a. $^+$Computed from the geometrical shapes of cut sections. ** Obtained from the modified cycle diagram in Fīgure 2b.

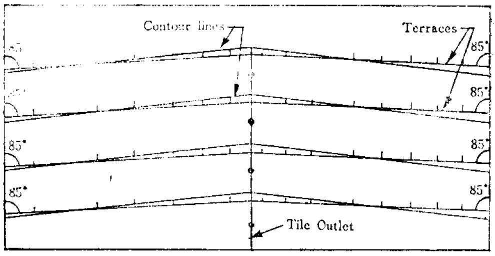
passes between the computer output and the probable scraper operations in the field. These extra passes have been determined by detailed study of scraper movements and represent a discrepancy between the computer model and reality. The difference, however, is negligible when compared with the total travel distance of the scraper.

An example of the use of the program in terrace design has been completed. Two different terrace systems, as shown in Figure 5, were chosen as examples for estimating the earthmoving cost in terrace construction. The Terrace I system accomodates a deep depression in the middle; consequently, it requires more soil movement toward the middle of the terraces than does the Terrace Ⅱ system, which more closely follows the contour lines.

Example solutions using the typical input data reveal some general conclusions about the earthmoving cost for terrace construction. Tables 5 and 6 compare the earthmoving costs of the two different terraces, each having the three different base widths for 4-percent and 6-percent ground slopes, respectively. The results show that the costs of earthmoving increase with the base widths regardless of the type of terrace. Also, the costs of earthmoving for Terrace I are always greater than those for Terrace Ⅱ for the same base widths. The difference in earthmoving costs between the two different terraces appear to be even more significant with a 6-percent ground slope because the steeper ground slope requires a greater volume of fill for the same ridge height.



(a) terrace system Ⅰ



(b) terrace system Ⅱ

Fig. 5. Terrace layouts for the example field.

**Table 5. Comparison of the Earthmoving Costs with a 4-Percent Land Slope**

| System | Base width (m) | Terrace length (m) | Earthwork volume ($m^3$) | Total cost ($) | Cost per length ($/m) | Cost per volume ($/$m^3$) |
|---|---|---|---|---|---|---|
| Terrace Ⅰ | 4.5 | 360.00 | 424 | 449.08 | 1.2474 | 1.0592 |
| | 6.0 | 360.00 | 562 | 559.28 | 1.5536 | 0.9952 |
| | 9.0 | 360.00 | 926 | 868.00 | 2.4111 | 0.9374 |
| Terrace Ⅱ | 4.5 | 361.37 | 390 | 300.83 | 0.8325 | 0.7714 |
| | 6.0 | 361.37 | 518 | 381.72 | 1.0563 | 0.7369 |
| | 9.0 | 361.37 | 868 | 615.03 | 1.7019 | 0.7086 |

**Table 6. Comparison of the Earthmoving Costs with a 6-Percent Land Slope**

| System | Base width (m) | Terrace length (m) | Earthwork volume ($m^3$) | Total cost ($) | Cost per length ($/m) | Cost per volume ($/$m^3$) |
|---|---|---|---|---|---|---|
| Terrace Ⅰ | 4.5 | 360.00 | 636 | 708.97 | 1.9694 | 1.1147 |
| | 6.0 | 360.00 | 756 | 790.82 | 2.1967 | 1.0461 |
| | 9.0 | 360.00 | 1392 | 1300.56 | 3.6127 | 0.9343 |
| Terrace Ⅱ | 4.5 | 361.37 | 533 | 407.28 | 1.1270 | 0.7570 |
| | 6.0 | 361.37 | 650 | 486.19 | 1.3454 | 0.7480 |
| | 9.0 | 361.37 | 1320 | 919.82 | 2.5454 | 0.6968 |

Tables 5 and 6 indicate that current contractor methods of estimating the costs of earthmoving by either the volume of earthwork or by the length of terrace are not appropriate. There are sizable differences in the cost per volume and the cost per length between the two different terraces. Estimating the earthmoving costs by calculating scraper travel is considered to be satisfactory because it takes into account both the volume of earthwork and the topography of the field in its algorithm.

Tables 7 and 8 show the scraper work schedules obtained from the computer outputs for the two different terrace designs, each having the same base width. By giving the scraper operator information on where the scraper cycles should be formed, this scraper work schedule enables him to construct terraces more efficiently.

**Table 7. Scraper Work Schedule for a Terrace with the Base Width of 6.0m in Terrace System I** (on a 4-Percent Land Slope)

| Cycle | Starting station | Turning station | Cycle interval (m) | Cycle rotation | Soil volume ($m^3$) | Trips | Accumulated trips |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 45 | cw | 13.44 | 1 | 1 |
| 2 | 1 | 5 | 60 | cw | 14.58 | 2 | 3 |
| 3 | 1 | 6 | 75 | cw | 10.87 | 4 | 4 |
| 4 | 1 | 7 | 90 | cw | 17.53 | 2 | 6 |
| 5 | 2 | 8 | 90 | cw | 23.59 | 3 | 9 |
| 6 | 2 | 9 | 105 | cw | 30.14 | 4 | 13 |
| 7 | 3 | 10 | 105 | cw | 37.61 | 5 | 18 |
| 8 | 4 | 11 | 105 | cw | 46.65 | 6 | 24 |
| 9 | 5 | 12 | 105 | cw | 57.88 | 8 | 32 |
| 10 | 8 | 13 | 75 | cw | 64.97 | 9 | 41 |
| 11 | 16 | 13 | 45 | ccw | 35.35 | 5 | 46 |
| 12 | 17 | 13 | 60 | ccw | 18.36 | 2 | 48 |
| 13 | 18 | 13 | 75 | ccw | 24.18 | 3 | 51 |
| 14 | 19 | 14 | 75 | ccw | 26.01 | 3 | 54 |
| 15 | 20 | 14 | 90 | ccw | 3.085 | 4 | 58 |
| 16 | 21 | 14 | 105 | ccw | 31.78 | 4 | 62 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 17 | 22 | 15 | 105 | ccw | 3.53 | 5 | 67 |
| 18 | 23 | 16 | 105 | ccw | 34.79 | 5 | 72 |
| 19 | 24 | 17 | 105 | ccw | 37.07 | 5 | 77 |
| 20 | 25 | 19 | 90 | ccw | 42.23 | 7 | 84 |

**Table 8. Scraper Work Schedule for a Terrace with the Base width of 6.0m in Terrace System II** (on a 4-Percent Land Slope)

| Cycle | Starting station | Turning station | Cycle interval (m) | Cycle rotation | Soil volume ($m^3$) | Trips | Accumulated trips |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 45.00 | cw | 43.79 | 6 | 6 |
| 2 | 2 | 5 | 45.00 | cw | 17.92 | 2 | 8 |
| 3 | 3 | 6 | 45.00 | cw | 20.26 | 3 | 11 |
| 4 | 4 | 7 | 45.00 | cw | 18.34 | 2 | 13 |
| 5 | 4 | 8 | 60.00 | cw | 25.70 | 3 | 16 |
| 6 | ( | 9 | 60.00 | cw | 28.92 | 4 | 20 |
| 7 | 7 | 10 | 45.00 | cw | 28.01 | 4 | 24 |
| 5 | 8 | 11 | 45.00 | cw | 29.75 | 4 | 28 |
| 9 | 9 | 12 | 45.00 | cw | 34.19 | 5 | 33 |
| 10 | 15 | 12 | 46.37 | ccw | 77.15 | 11 | 44 |
| 11 | 17 | 14 | 45.00 | ccw | 44.11 | 6 | 50 |
| 12 | 18 | 15 | 45.00 | ccw | 24.70 | 3 | 53 |
| 13 | 19 | 16 | 45.00 | ccw | 25.88 | 3 | 56 |
| 14 | 20 | 16 | 60.00 | ccw | 27.46 | 4 | 60 |
| 15 | 21 | 18 | 45.00 | ccw | 22.73 | 3 | 63 |
| 16 | 22 | 19 | 45.00 | ccw | 24.97 | 3 | 66 |
| 17 | 23 | 20 | 45.00 | ccw | 27.22 | 4 | 70 |
| 18 | 24 | 21 | 45.00 | ccw | 22.74 | 3 | 73 |
| 19 | 25 | 23 | 30.00 | ccw | 25.02 | 4 | 77 |

## CONCLUSIONS

As a result of the studies described in this paper, the following conclusions have been drawn:

1. A method for estimating the earthmoving cost by a self-loading scraper can be developed based on scraper travel for balanced cut-and-fill terraces.

2. Computer methods are necessary to determine scraper cycles and to estimate the earthmoving cost.

3. The solution of an example problem using the developed computer model, showed satisfactory modeling for estimating the earthmoving cost.

4. This computational method can give a construction contractor a guide for the efficient use of scrapers in terrace construction.

## REFERERENCES

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