不規則地形配合控制高度之土地重整法

Land Forming Design For A Non-Rectangular Shaped Field With Elevation Controls

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中 文 摘 要

世界各地低窪地區的土地重整是指高低不平、排水不良、灌漑水之分配不均勻或土地劃分不適於機耕等等之農田，改變其地表坡度使利於灌漑排水、塡平窪地及不必要的溝渠，配合機耕所需之農田條件等而言。以往各種設計方法着重於矩形的農田，但實際上矩形農田並不多，極大部份的農田形狀是不規則的。再則，目前農田中之灌漑入水口，或排水之出口因構造物等關係已固定，照目前的各種設計方法尙無法保持其特定地點的高度而行設計，因此在土地重整後須改變許多附帶工程，而使重整的工程費增加。本文介紹用電腦技術設計不規則地形之土地重整法，這種重整法尙能自動調節農田中特定地點之保持而重新設計。每一地區之設計都含有五種不同的設計法，同時提供工程設計者每種方法之挖方、塡方、挖塡方之比例，和工程費用等等資料。

INTRODUCTION

Land forming is a relatively new practice in the humid regions of the United States. According to Quackenbush (3), land modification as a water management practice was seldom performed in the eastern part of the United States before 1950. However, irrigation is steadily growing and surface drainage is a continuing problem in humid regions.

In 1971, Shih and Kriz (6) developed a land forming design procedure called the symmetrical residuals method. This method, along with previously existing methods (5), was developed for the design of rectangularly shaped fields. However, many fields in the Southeast area are nonrectangular shaped. Also, the existing design methods have limited application because of the inability to impose certain desired controls on the design. In many humid areas, the elevations of field boundaries are restricted by the location of a drainage outlet, an irrigation intake, or a common boundary with another field. There may also be a need for additional earthwork to build terraces and fill gullies or old drainage ditches, or extra earthwork may be available from the construction of new waterways or drainage ditches. An economical land forming design procedure must be capable of accomodating these variations that frequently occur especially in humid areas. The design procedure presented herein contains such features.

OBJECTIVES

The specific objectives are: (1) To develop equations for determining the centroid location in the row and cross row directions for nonrectangular shaped fields, (2) To develop new equations for calculating earthwork volume for an nonrectangular shaped field, (3) To present additional features that can be incorporated into designs, including elevation control and earthwork calculations for filling and constructing ditches, and (4) To present a systematic computer procedure for obtaining the five types of land forming design on a nonrectangular shaped field.

DESIGN PROCEDURE

Shih and Kriz (5) introduced five types of land forming designs: Type I-uniform slope (plane surface) with row and cross row drainage; Type II-variable slope with row and cross row drainage; Type III-uniform slope in individual rows in the row direction and variable slope in the cross row direction with row and cross row drainage; Type IV-uniform slope in individual rows with row drainage and a minimum and maximum allowable cross row slope (no cross row drainage); and Type V-variable slope in individual rows with row drainage and a minimum and maximum allowable cross row slope (no cross row drainage).

Figure 1 illustrates the field layout where station A_{11} must be the station with the highest elevation in the final design.

Cross row direction-Y →

A_{00}						Sum
Row direction-X ↓	A_{11}	A_{12}	A_{13}	• • •	A_{1m_1}	$\sum_{j=1}^{m_1} A_{2j}$
	A_{21}	A_{22}	A_{23}	• • •	A_{2m_2}	$\sum_{j=1}^{m_2} A_{2j}$
	A_{31}	A_{32}	A_{33}	• • •	A_{3m_3}	$\sum_{j=1}^{m_3} A_{3j}$
	• • •	• • •	• • •		• • •	• • •
	$A_{n_1 1}$	$A_{n_2 2}$	$A_{n_3 3}$	• • •	$A_{n_m m_n}$	$\sum_{j=1}^{m_n} A_{ij}$
Sum	$\sum_{i=1}^{n_1} A_{i1}$	$\sum_{i=1}^{n_2} A_{i2}$	$\sum_{i=1}^{n_3} A_{i3}$	• • •	$\sum_{i=1}^{n_m} A_{ij}$	$\sum_{i=1}^{n_m} \sum_{j=1}^{m_n} A_{ij}$

Figure 1. Field layout for computational purposes. Station A_{11} must be the station with the highest proposed design elevation.

Determination of Best Slope

The term "best Slope" that is referred to hereafter in all types of design is defined as the slope calculated using the symmetrical residuals method of design. It is based on residual properties, Newton's divided difference interpolation procedure, and statistical properties of the best statistic with unbiased estimate and minimum variance (6). The elevatioins. used to determine the best slope in all types of design are either the initial field elevations or elevations previously calculated while determining one of the other types of design (4)

The best slope, b, in the row direction for an nonrectangular shaped field is determined by

$$b = \sum_{j=1}^{m_e} w_{j_e} b_{j_e} + \sum_{j=1}^{m_o} w_{j_o} b_{j_o}, \qquad (1)$$

in which w_{j_e} = a weighting factor in the j^{th} row that has an even number of stations, n_{j_e}, or

$$w_{j_e} = \frac{n_{j_e}^3}{\sum_{j=1}^{m_e} n_{j_e}^3 + \sum_{j=1}^{m_o} (n_{j_o}+1)^2 (n_{j_o}-1)}; \qquad (2)$$

w_{j_o} = a weighting factor in the j^{th} row that has an odd number of stations, nj_o, or

$$w_{j_o} = \frac{(n_{j_o}+1)^2 (n_{j_o}-1)}{\sum_{j=1}^{m_e} n_{j_e}^3 + \sum_{j=1}^{m_o} (n_{j_o}+1)^2 (n_{j_o}-1)}; \qquad (3)$$

m_e = the number of rows that have an even number of stations; m_o = the number of rows that have an odd number of stations: bj_e = the best slope of the j^{th} row that has an even number of stations, or

$$b_{j_e} = \frac{4\left[\sum_{i(=n_j/2)+1}^{n_j} A_{ij} - \sum_{i=1}^{n_j/2} A_{ij}\right]}{n_j^2 d}; \qquad (4)$$

b_{j_o} = the best slope of the j^{th} row that has an odd number of stations, or

$$b_{j_o} = \frac{4\left[\sum_{i=(n_j+3)/2}^{n_j} A_{ij} - \sum_{i=1}^{(n_j-1)/2} A_{ij}\right]}{(n_j^2-1)d}; \qquad (5)$$

n_j = the number of stations in the j^{th} row; A_{ij} = the original field elevation; and d = the grid spacing generally taken as 100 feet.

A similar expression for the best slope, c, is the cross row direction is

$$c = \sum_{i=1}^{n_e} w_{i_e} c_{i_e} + \sum_{i=1}^{n_o} w_{i_o} c_{i_o} , \qquad (6)$$

in which w_{i_e} and w_{i_o} = the weighting factors in the i^{th} cross row that has an even number, m_{i_e} or odd number, m_{i_o}, of stations, respectively; n_e and n_o = the number of cross rows that have an even or odd number of stations, respectively; and c_{i_e} and c_{i_o} = the best slopes of the i^{th} cross row that has an even or odd number of stations, respectively. Equations (1) through (6) were developed by Shih and Kriz (9).

Centroid Elevation and Location:

The centroid elevation of the field, A_c, is

$$A_c = \frac{\sum_{i=1}^{n_m} \sum_{=1}^{m_n} A_{ij}}{\Sigma n_m m_n} , \qquad (7)$$

in which $\Sigma n_m m_n$ = the total number of stations in the field. A graphical method for determining the centroid location in a nonrectangular shaped field was presented by Chugg (2).

A new technique using each row or cross row as a singular plane to determine the centroid location of the row and cross row direction was developed herein. Figure 2 shows the layout for a nonrectangular shaped field.

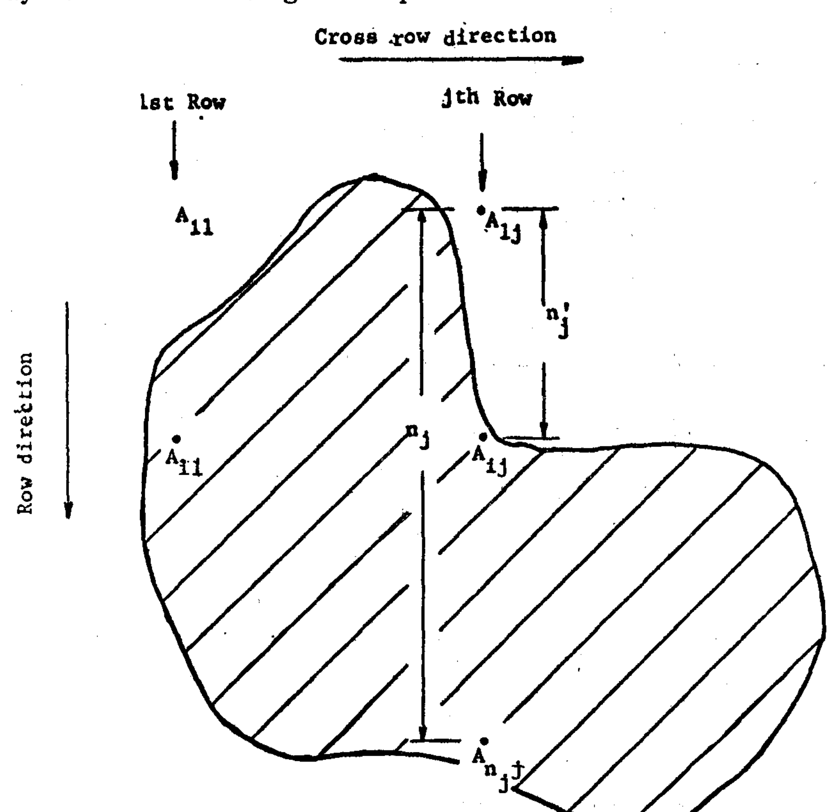


Figure 2. Layout of nonrectangular shaped field.

The centroid location, X_c, in the row direction is

$$X_c = \sum_{j=1}^{m_n} \left[\frac{n_j(n_j+1)}{2} - \frac{n'_j(n'_j+1)}{2} \right] \Big/ \Sigma n_m m_n, \qquad (8)$$

in which n_j = the total number of stations in the j^{th} row plus the number of stations, n'_j, between A_{11} and A'_{11}. A'_{11} is in the same cross row with the first station in the j^{th} row.

The centroid location, Y_c, in the cross row direction is

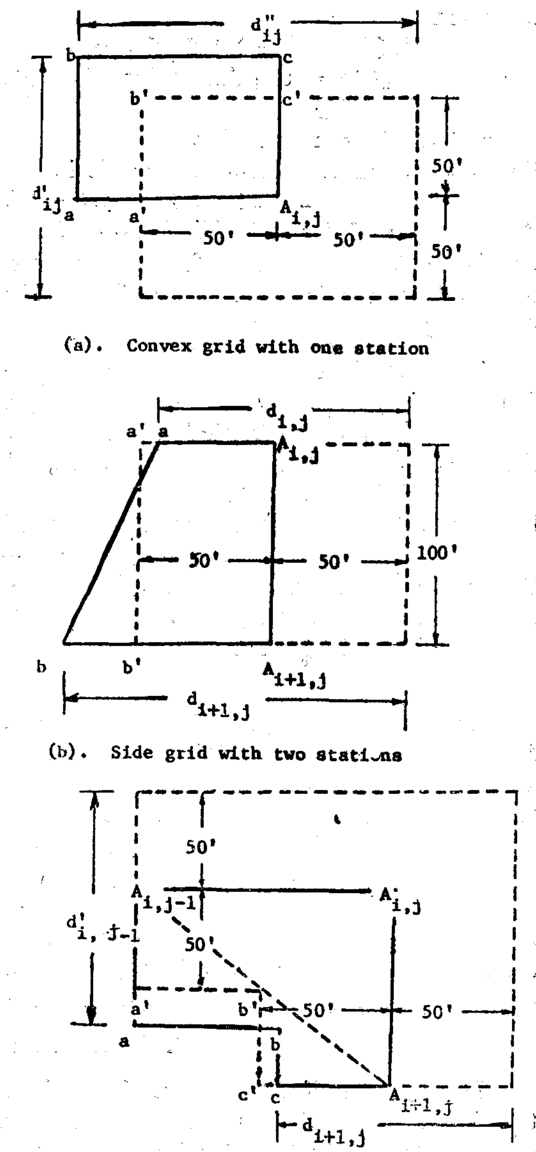
$$Y_c = \sum_{i=1}^{n_m} \left[\frac{m_i(m_i+1)}{2} - \frac{m'_i(m'_i+1)}{2} \right] \Big/ \Sigma n_m m_n, \qquad (9)$$

in which m_i, = the total number of stations in the i^{th} cross row plus the number of stations, m'_i, between A_{11} and A'_{1j}. A'_{1j} is in the same row with the first station in the i^{th} cross row.

MODIFIED EARTHWORK CALCUATION

The grid system used for land forming design of a rectangular field has interior and exterior grids. The former exist within the field and the latter along the field boundaries. The volume of earthwork in both the interior grids and the exterior grids with 50-foot distances from the stations to field boundaries can be calculated by the end grid area method (7). Techniques to better estimate earthwork volumes for nonrectangular grids are developed below.

In order to use the end grid area method for nonrectangular shaped fields, the exterior grids are divided into three categories. Category 1 is called a convex grid. It is actually a corner of the field containing only one station as shown in Figure 3a. Category 2, called a side grid, contains only two stations in the grid as shown in Figure 3b. Category 3 is called a concave grid. It has three stations belonging to the grid system of the field as shown in Figure 3c.



(a). Convex grid with one station

(b). Side grid with two stations

(c) Concave grid with three stations

Figure 3. - Geometry of Varied Boundary Grid

Convex Grid

As shown in Figure 3a, let $d=\sqrt{d'_{i,j} \cdot d''_{i,j}}/100$, in which $d'_{i,j}$ and $d''_{i,j}$ are the distances from the field boundary (row and cross row direction) to the station $A_{i,j}$ plus 50 ft. The range of d is allowed to vary from 0.5 to 1.5. If the grid only includes the area a' b' c'$A_{i,j}$, i. e. if d=1, the earthwork volume is calculated by the end grid area method. If the value of d is not equal to one, the earthwork volume is calculated by the function, f_v (d). This function is obtained by using the Lagrange Interpolation Formula (1) i. e.

$$f(d)=\sum_{k=0}^{n} \ell_k(d)f_k+R_n(d), \qquad (10)$$

in which

$$\ell_k(d) = \frac{\Pi_n(d)}{(d-d_k)\,\Pi'_n(d_k)}, \qquad (11)$$

in which

$\Pi_n(d) = (d-d_0)(d-d_1)\cdots(d-d_n)$,

$\Pi'_n(d)$ = the derivative of $\Pi_n(d)$,

$f_k = f(d_k)$,

and $R_n(d)$ = remainder.

For the grid area abc$A_{i,j}$, the result is

$$f_v(d) = 1 - 4d + 4d^2 = (2d-1)^2. \qquad (12)$$

For example, if d equals 0.5, 0.6,……, 1.5, the corresponding functing function, f_v (d) is 0,1/25,……, 4, respectively. To determine the earthwork volume, f_v(d) is multiplied by the earthwork volume for a 100-foot as determined by the end grid area method.

Side Grid

As shown in Figure 3b, let d = $(d_{i,j} + d_{i+1,j})/2 \times 100$, in which $d_{i,j}$ and $d_{i+1,j}$ = the distances from the field boundary to $A_{i,j}$ and $A_{i+1,j}$ plus 50 ft., respectively. The range of $d_{i,j}$ and $d_{i+1,j}$ are varied from 0.5 to 1.5, If the grid contains the area a'b'$A_{i+1,i}$' then d=1, the earthwork quantities are calculated by the end grid area method. If the value of d is not equal to one, f_s (d) is used to calculate the earthwork volume. Equations (10) and (11) are used to determine f_s(d). The result is

$$f_s(d) = 2d-1. \qquad (13)$$

For example, when d equals 0.5, 0.6, …… 1.5, f_s (d) is 0, 0.2,……, 2, respectively. The earthwork volume is equal to f_s (d) times the earthwork volume for a 100-foot grid as determined by the end area method.

Concave Grid

As shown in Figure 3c, let d = $(d_{i,j-1}+d_{i+1,j})/2 \times 100$, where $d_{i,j-1}$ and $d_{i+1,j}$ = the distances along the station $A_{i,j-1}$ and $A_{i+1,j}$ plus 50 fr., respectively. The ranges of $d_{i,j-1}$ and $d_{i+1,j}$ are varied from 0.5 to 1.5. The earthwork calculation is similar to the convex grid case except that the grid for the case of d=1 includes the area a'b'c' $A_{i+1,j}A_{i,j}A_{i,j-1}$. If the value of d is other than one, the earthwork volume is determined by the function, f_c(d). Equations (10) and (11) are used to determine f_c(d). The result is

$$f_c(d) = (2d+1)/3. \qquad (14)$$

As in the previous methods, the earthwork volume is determined by multiplying f_c(d) times the volume for a 100-foot grid as determined by the end grid area method. For example, when d=0.5, fc(d) is 2/3 of the earthwork volume shown in the SCS table (8).

COMPUTER PROGRAMS

The systematic flów chart shown in Figure 4 illustrates a procedure for obtaining the five types of design with several options. The program options include elevation controls for irrigation intakes, drainage outlets and adjacent field boundaries, and methods for disposing of extra earthwork or using earthwork from the field to fill ditches and gullies. This procedure has been programmed in the Fortran IV language for use on an IBM system 370 Model 165 computer.

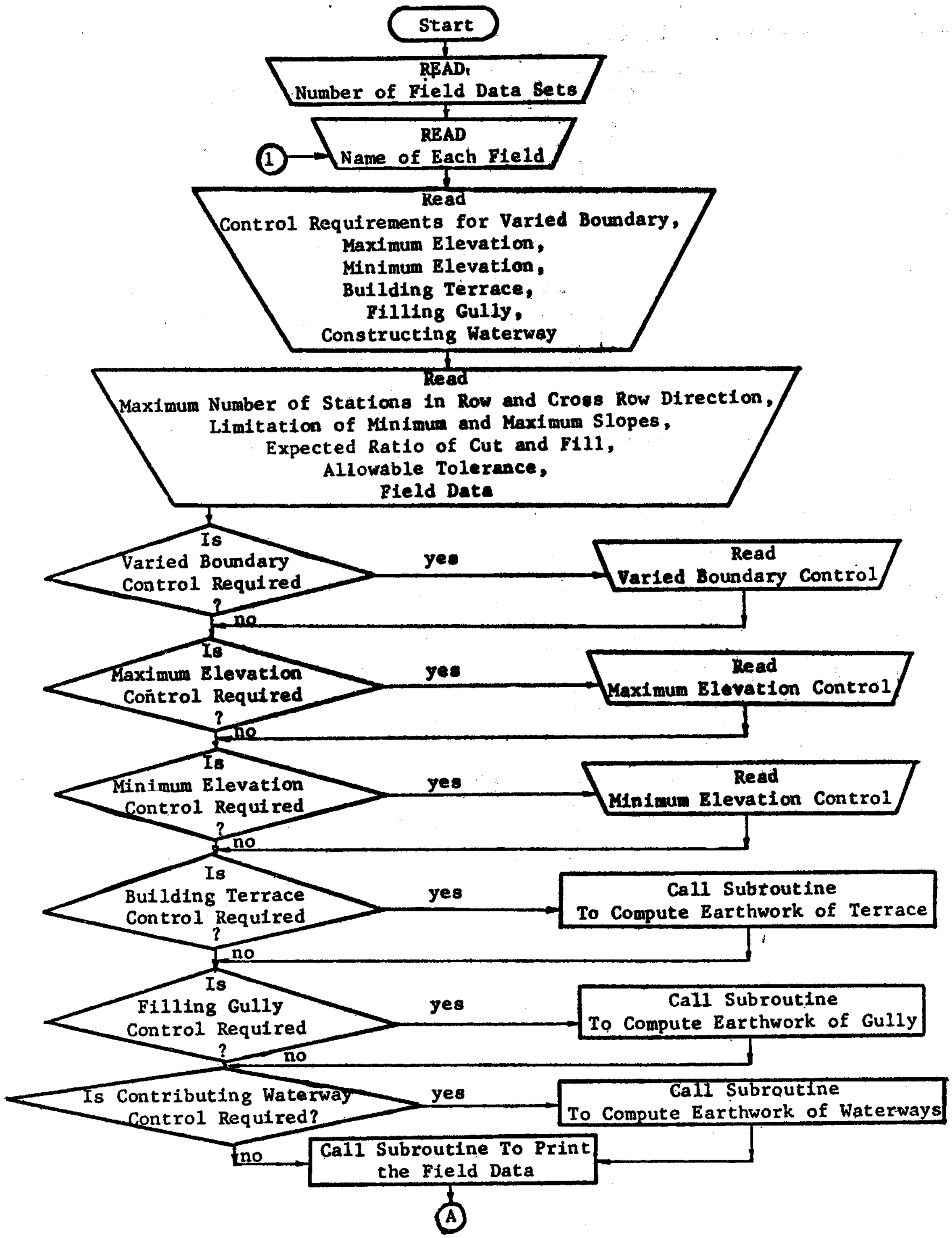


Figure 4. Systematic flow chart for the land forming design on irregular shaped field.

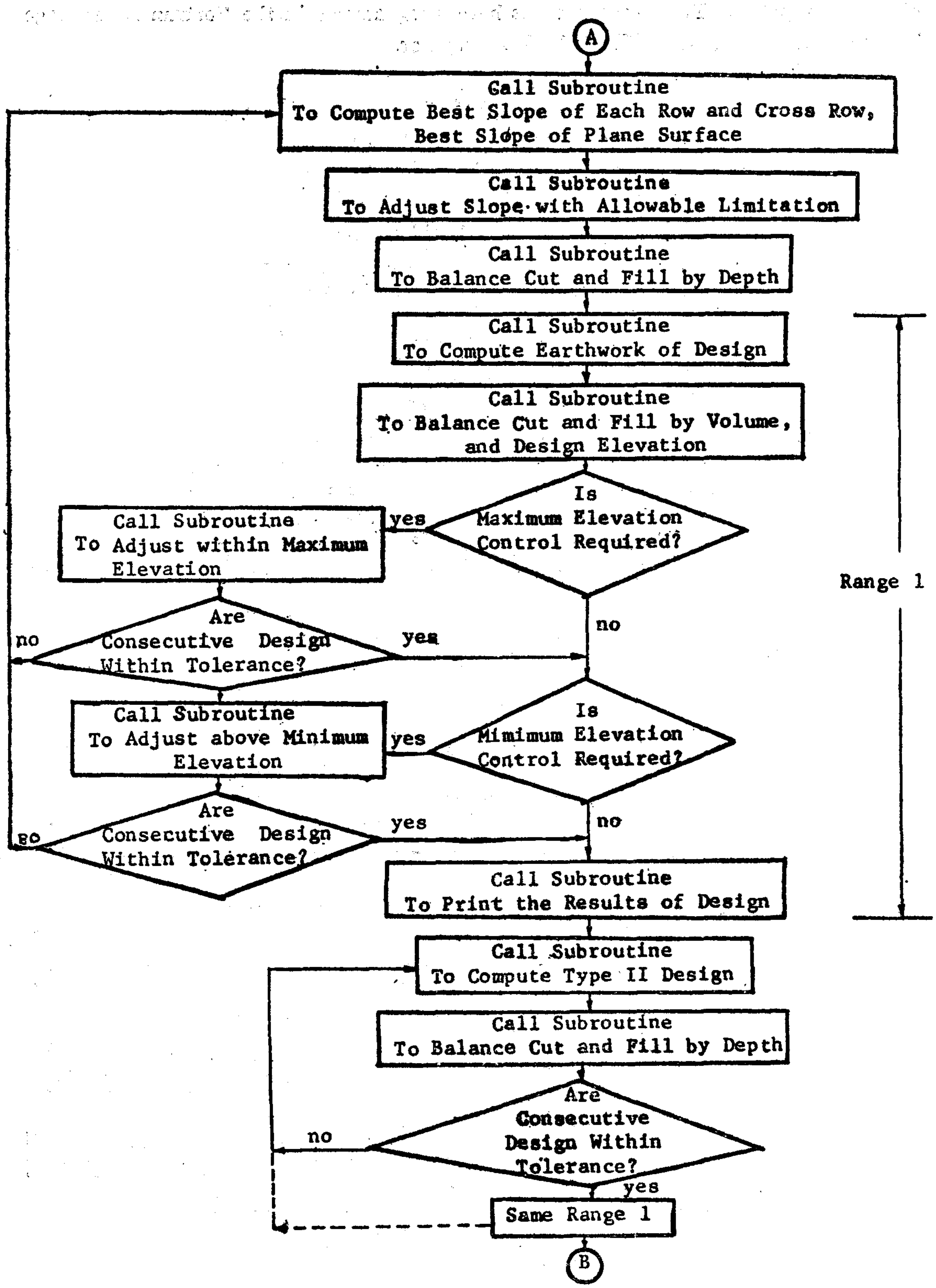


Figure 4. (Continued)

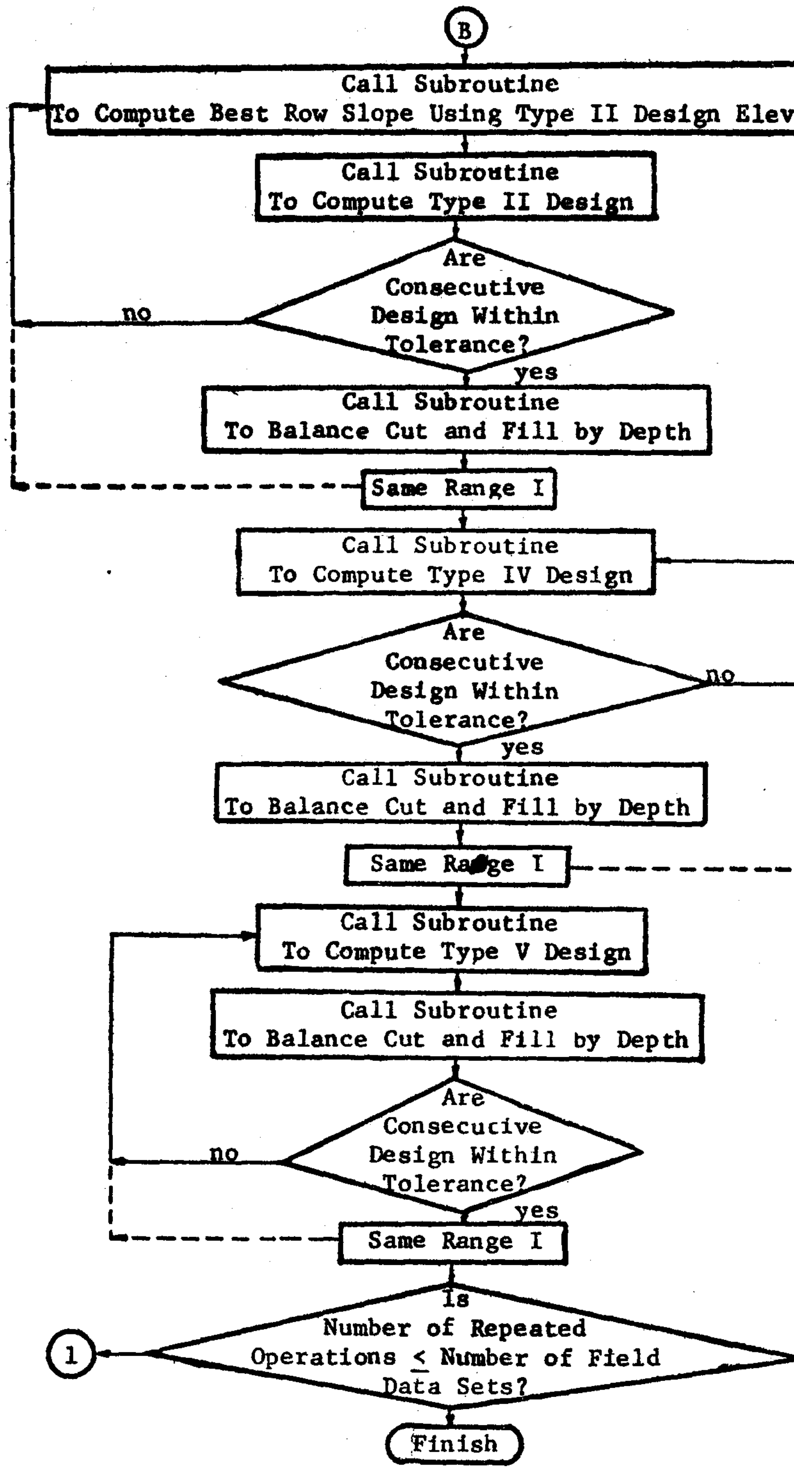


Figure 4. (Continued)

Type I *Design-Uniform slope (plane surface) with row and cross row drainage.*

The first step in the design procedure is to determine the best slope within the allowable slope limitations for the row and cross row directions by the symmetrical residuals method. The cut-fill ratio is first balanced by depth and then by volume, The total volume of cut used in the cut-fill ratio calculations is the sum of each grid volume of cut plus any volume of cut trans-ported from the field. The total volume of fill is the sum of each grid volume of fill plus any volume of fill transported onto the field

The second step is to compare the design elevation at each boundary station with the elevations for an irrigation intake and/or specified maximum boundary elevations. Where the design elevations exceed specified maximums, they are made equal to them. After each boundary station has been checked and adjusted, the summation of the absolute values of the differences between the before and after adjustments is compared to an arbitrary tolerance. A tolerance of 0.1 was used in this study. If the absolute values of the differences is greater than the tolerance, the third step is followed. If they are less than or equal to the tolerance, the fourth step is followed.

The third step is to redesign the plane surface using elevations for the boundary stations determined in the second step and to check whether the new design elevations for the boundary stations are between specified maximum and minimum boundary elevations. If adjustments are required, the procedure is twofold. First, adjustments are made to satisfy any specified maximum or minimum elevation requirements. The adjustment procedure is initiated from station (1,1). If the elevation at station (1,1) is greater than a specified maximum elevation, the design elevation is made equal this elevation. If the design elevation at station (2,1) is greater than the specified maximum elevation at station (1,1) minus the minimum allowable row slope, the design elevation is made equal to the latter. If station (2,1) has a specified maximum elevation and the new elevation at station (2,1) is greater than this specified maximum, the new design elevation is made equal to the specified maximum elevation. Stations (3,1), (4,1),……(N,1) are checked and adjusted in a similar manner.

The second procedure checks whether the stations in the first row meet the requirements of a specified minimum elevation. If the elevation at station (N,1) is less than a specified minimum, the design elevation (N,1) is made equal to the specified minimum elevation. If the elevation at station (N-1, 1) is less than the specified minimum elevation at station (N,1) plus the minimum allowable row slope the design elevation is made equal to the latter. If station (N-1,1) has a specified minimum elevation and the new elevation at station (N-1,1) is less than this specified minimum, the new elevation is made equal to the specified minimum elevation. Stations (N-2,1), (N-3,1),…… (N-(N-1),1) are checked and adjusted in a similar manner.

After all stations in first row have been checked and/or adjusted, row 2, row 3……, row M are checked and/or adjusted for both specified maximum and minimum elevations until all stations in the field have been considered. The first and second steps are repeated until the summation of the absolute values of the differences between the before and affer adjustments is less than or equal to the tolerance.

The fourth step is to compare the design elevation at each boundary station with the specified minimum elevations. Where the design elevations are less than the specified minimums, they are made equal to them. After each boundary station has been checked and adjusted, the summation of the absolute values of the differences between the before and after adjustments is compared to an arbitrary tolerance. If the absolute values of the differences are greater than the tolerance, the fifth step is followed. If they are less than or equal to the tolerance, the sixth step is followed.

The fifth step is similar to the third step except that checks to determine whether the new design elevations for the boundary stations are between the specified maximum and minimums start at station (N,M). After elevation adjustments are made to satisfy any minimum elevation requirements, requirements for specified maximum elevations are checked beginning with station (1,M). After all stations in the last row have been checked and/or adjusted, row (M-1), row (M-2),…… row (M-(M-1)) are checked and/or adjusted for both specified maximum and minimum elevations until all stations in the field have been considered. The first three steps are then repeated until the summation of the absolute values of the differences between the before and after adjustments is less than or equal to the tolerance.

The sixth step is to compare the summation of the absolute values of the differences between the before and after adjustments in the second and fourth steps with a specified tolerance. If the difference is greater than the tolerance, the second and fourth steps are repeated until the difference is less than or equal to the tolerance.

Type Ⅱ Design–Variable slope with row and cross row drainage.

The first step is to design the field according to procedures introduced by Shih and Kriz (5). The second step is the same as the second step in the Type I design procedure. The third step is the same as the third step in the Type I design procedure except that the new elevation established at any station is used when comparisons are made back to that station. After all stations have been checked and adjusted if necessary, the cut-fill ratio is balanced by depth and then by volume. Because all stations are increased or decreased by some amount in the balancing procedure, a better fit to the original field surface while at the same time satisfying any elevation controls is obtained by redesigning the entire field. Therefore, the first and second step are repeated until the fourth step is reached. It is the same as the fourth step in the Type I design procedure, The fifth step is the same as the fifth step in the Type I design procedure except that the new elevation at any station is used when comparisons are made back to that station. The first four steps are repeated until the sixth step is reached. It is the same as the sixth step in the Type I design procedure.

Type Ⅲ Design–uniform slope in individual rows in row direction and variable slope in the cross row direction with row and cross row drainage.

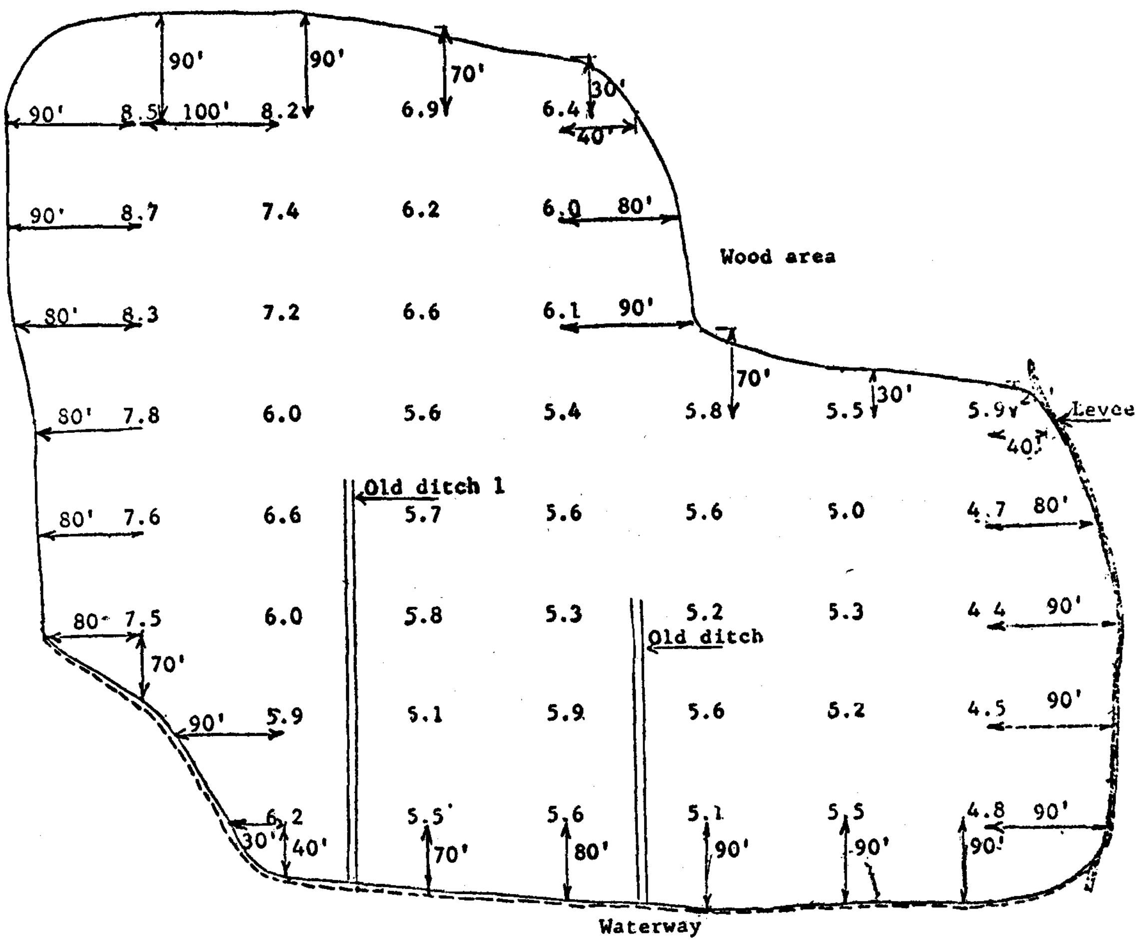
All steps are similar to those in the Type I design procedure except for modifications inherent in the Type Ⅲ design which are taken into account in first step.

Type Ⅳ Design–Uniform slope in individual rows with row drainage and a minimum and *maximum allowable cross row slope (no cross row drainage).*

All steps are similar to those in the Type I design procedure except for modifications inherent in the Type IV design which are taken into account in the first step.

Type V Design-Variable slope with row drainage and a minimum and maximum allowable cross row slope (no cross row drainage).

All steps are similar to those in the Type II design procedure except for modifications inherent in the Type V design which are taken into account in the first step.



Item	Symbol	Length ft.	Average cross section area sq. ft.
Levee		520	27
Old ditch 1		400	10.5
Old ditch 2		300	6
Waterway		860	32

Average cross section shape

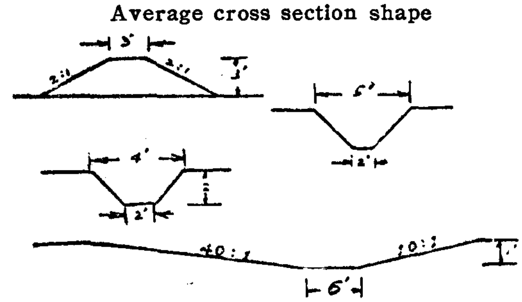


Figure 5. Layout of a nonrectangular shaped field

AN EXAMPLE

In order to determine the effects of the different controls on computer run time, computed field size, earthwork volume, percent of stations with cuts over 0.5-foot, and field slopes, six different cases were studied: (1) No controls-original field elevations and 50-foot boundarie; (2) Variable boundary control-original field elevations with variable boundaries as shown in Figure 5; (3) Irrigation intake or maximum elevation control-Case 1 plus a maximum 7.5-foot elevation permitted for the first station in each row; (4) Drainage outlet or minimum elevation control -Case 1 plus a minimum 5.0-foot elevation specified for last station in each row; (5) Extra volume of earthwork control-Case 1 plus determination of earthwork for levee and waterway plus filling old ditches as shown in Figure 5; and (6) All controls.

The data for the design of a nonrectangular shaped field with variable distances to the boundary is presented in Figure 5. All design slopes in the row direction are limited to a range of 0.1 to 0.5% and in the cross row direction to 0.0 to 1.0%. The cut to fill ratio is allowed to range from 1.25 to 1.35.

Table 1. Comparison of computer time*, volume of earthwork, over 6″ cut and slopes in 5 types of design for different control conditions.

Results of Control \ Different Control			Case 1: Without any control	Case 2: Control the vary boundary	Case 3: Control the irrigation intake elevation	Case 4: Conrol the drainage outlet elevation	Case 5: Control the extra volume of earthwork	Case 6: Control the all conditions
Field area in acres			10.331	11.926	10.331	10.331	10.331	11.926
Computer time in seconds			3.3	3.7	5.5	6.1	4.2	16.8
Type I	A[a]		3366	3950	3380	4215	4385	6122
	B[b]		17.78	17.78	17.78	20.00	17.78	20.00
	Slopes in percent	Row	0.166	0.166	0.149	0.106	0.166	0.112
		Cross Row	0.358	0.358	0.344	0.218	0.358	0.217
Type II	A		159.6	1771	2539	1939	2591	4380
	B		4.44	2.22	13.33	6.67	4.44	15.56
Type III	A		2044	2283	2781	2365	3032	4671
	B		6.67	6.67	13.33	8.89	6.67	17.78
	Row Sloqes in percent	1	0.28	0.27	0.10	0.32	0.28	0.10
		2	0.25	0.25	0.21	0.27	0.25	0.22
		3	0.21	0.21	0.21	0.22	0.21	0.20
		4	0.14	0.13	0.12	0.15	0.14	0.12
		5	0.20	0.19	0.16	0.16	0.20	0.16
		6	0.16	0.15	0.13	0.11	0.16	0.12
		7	0.15	0.14	0.10	0.10	0.15	0.10

Type IV	A		0691	1933	2606	2032	2677	4525
	B		0	0	11.11	6.67	0	11.11
	Row slopes in percent	1	0.29	0.29	0.10	0.29	0.29	0.10
		2	0.29	0.29	0.24	0.29	0.29	0.24
		3	0.21	0.21	0.22	0.22	0.21	0.22
		4	0.10	0.10	0.10	0.10	0.10	0.10
		5	0.12	0.12	0.12	0.12	0.12	0.12
		6	0.10	0.10	0.10	0.10	0.10	0.10
		7	0.10	0.10	0.10	0.10	0.10	0.10
Type V	A		1474	1704	2498	2018	2484	4345
	B		0	0	11.11	6.67	0	11.11

* IBM System 360 Model 75 computer was used in this comparison.

[a]A = volume of cut in cubic yards.

[b]B = over 0.5 foot cut in percent.

The results shown in Table 1 can be summarized as follows: (1) the area of the field with variable boundary control is 15% larger than without the control; (2) the computer run time is not significantly affected (about 10%) by the variable boundary control; (3) the computer run times without controls are 54% and 78% of computer run times when elevation and extra volume of earthwork controls, respectively, are used; (4) the computer run time is five times greater for all controls than for no controls than for no controls; (5) the general order for the percentage of cut over 0,5-foot in all six cases is Type I > Type III > Type II > Type IV > Type V; (6) the quantity of earthwork is 10-17% less for no controls than for variable boundary control; and (7) the design slopes are different between designs with and without elevation controls.

Walker and Lillard (9) showed that in eastern Virginia an average of approximately six man-hours per acre are required for surveys and computations in land forming design for only the Type I design. Acoording to experience gained in surveying 4000 acres in North Carolina the average time requirement for land forming surveys is about one man-hour per acre. The design time for a tenacre field requires apotely approximately two hours for converting rod reading to elevations, filling computer forms, keypunching, and computer executive work. The computer run time for combining the six cases into one computer run was 65 seconds.

CONCLUSIONS

Land forming design procedures for nonrectangular shaped fields have been successfully developed. A systematic flow chart is presented to show the design procedure for nonrectangular shaped fields that includes five types of design with options for variable boundary control and elevation control, and filling and constructing ditches.

New equations were developed for determining the centroid locations for nonrectangular shaped fields. The exterior boundary grids of nonrectangular shaped fields were divided into three categories; i, e. convex grid, side grid and concave grid; and the corresponding equation for obtaining the volumes earthwork were also developed.

An example used in this study points to the following results. Taking the variable boundary into account gives more accurate field areas and quantities of earthwork without a significant increase in computer run time. Elevation controls increase the computer run time and also change the final design slope. The general order of earthwork volume and of cuts over 0.5-foot are Type I > Type III > Type II > Type IV > Type V.

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