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Section 15

IRRIGATION

Chapter 12

LAND LEVELING

Soil Conservation Service
United States Department of Agriculture

SCS NATIONAL ENGINEERING HANDBOOK

SECTION 15

IRRIGATION

CHAPTER 12--LAND LEVELING

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General

Description.
Land leveling or land grading for irrigation is modifying the surface relief of a field to a planned grade to provide a more suitable surface for efficiently applying irrigation water.

Normally land leveling requires moving a lot of earth over several hundred feet. This should not be confused with land planing, land smoothing, or land floating. They are usually accomplished with special equipment to eliminate minor irregularities, and they do not change the general topography of the land surface.

Rough grading is removing knolls, mounds, or ridges and filling pockets or swales in a field that is not to have a planned grade. Often no construction stakes are set and reliance is placed on the "eye" of the equipment operator to obtain the desired field surface. Rough grading is seldom adequate for lands to be surface irrigated.

Criteria for Land Leveling.
Criteria for land leveling will be influenced by the soil, slope, climate, crops to be grown, methods of irrigation, and the desires of the farmer.

Land leveling should never be planned without knowing the soil-profile conditions and the maximum cut that can be made without seriously affecting agricultural production. Shallow soils that require strict limitations on permissible depth of excavation do not permit much freedom to the designer. They pose a difficult problem when combined with undulating topography or steep slopes.

The climate of an area often places certain limits on slope to prevent erosion from rainfall or to provide adequate drainage. Also crops to be grown need to be known since they will affect the irrigation methods selected and will provide an idea as to the amount of leveling needed. Intensively cultivated crops such as vegetables may justify a high leveling cost whereas a hay crop in an area with a short growing season may warrant a much smaller investment.

Each method of irrigation has limitations. When several methods of irrigation are to be used on the same field, the requirements of the most restrictive must be met. The level border method is the most restrictive of all irrigation methods. In general, flooding methods have the strictest cross-slope requirements.

The desires of the farmer must also be known in selecting the design standards for a specific job. Minimum conservation-irrigation standards must be met. Oftentimes the farmer desires to have a still better job that will save on labor and permit better farming practices. The engineer should attempt to design the best job the farmer is willing to accept and pay for. Usually the standards of the farmers go up from year to year, and a job that is perfectly satisfactory today may be considered substandard tomorrow. Many fields have been leveled and re-leveled several times, each time to a higher standard. Obviously the number of times a field is leveled should be held to a minimum. Therefore, it is desirable to design as refined a job as the soil and farmer will permit.

It is generally accepted that the most desirable field surface for agricultural production is a plane surface on a nearly level grade. Likewise, the least desirable is one with such surface relief that irrigation can barely be accomplished and that unusually good management is required to obtain even fair irrigation water efficiencies.

Table 12-1 is a classification of surface relief as it affects irrigation. In some areas Class A_1 might be the only one to consider, whereas in others with shallow soils and steep slopes, Class E may be the best physically obtainable. The least restrictive class permissible may be established at a State level based on climate and other conditions.

Class C is the lowest usually considered satisfactory for conservation irrigation by surface methods. When it is impossible, however, to bring the surface to this standard, special justification should be present before surface methods are recommended. Usually sprinkler methods are best for these sites.

Preparatory Steps.

Land leveling is usually accomplished on a field by field basis. It is extremely important, therefore, to study the entire farm before attempting any leveling.

Land leveling is probably the most intensive practice that is applied to agricultural lands, and much expense can be saved by carefully dividing the farm into areas that have about the same slope and soil characteristics. These areas will provide a basis for selecting the proper field arrangement.

Table 12-1.--Relief classes for surface irrigated land.

Class	Irrigation slope 1/	Cross slope	Possible irrigation water efficiencies	Irrigation operation labor requirement	Method limitations	Leveling requirement
A_1	Uniform but not more than 0.05 percent	None	High	Very low	None	None
A_2	Uniform				Length of level borders is restricted.	
B_1		Uniform but not more than 0.3 percent			Length of level borders restricted. Border widths are restricted.	Leveling desirable to increase length or width of level borders.
B_2		Variable but not more than 0.3 percent		Low		Leveling desirable to reduce labor requirement.
B_3		Either uniform or variable and more than 0.3 percent but not more than 0.5 percent			Border widths are very restricted. Level borders not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils. Corrugations must have down-slope of at least four times cross slope.	
C_1	Fairly uniform - slopes have maximum grades not over twice minimum; concave slopes have maximum grade not over 1 1/2 times minimum. Undulating slopes not permissible.)	Uniform or variable	Good	Moderately low	Level borders not permissible.	Leveling desirable to reduce labor requirement and improve irrigation efficiencies.
C_2		Uniform or variable but not more than 0.5 percent			Border widths are very restricted. Level borders not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils. Corrugations must have down-slope of at least four times cross slope.	
C_3	Either uniform or fairly uniform as defined above	Either uniform or variable and more than 0.5 percent		Moderate to high	Applicable only for contour ditches or to cross slope or contour furrow irrigation within special limitations of furrow depth and soil texture.	
D_1	Variable but without level reaches or reverse grades	Variable but not more than 0.3 percent	Poor	Moderate	Border widths are restricted. Level borders or corrugations not permissible.	Leveling required for conservation irrigation.
D_2		Variable but not more than 0.5 percent		High	Border widths are very restricted. Level borders or corrugations not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils.	
E		Variable and more than 0.5 percent	Very poor	Very high	Applicable only for contour ditches or furrows within special limitations of furrow depth and soil texture.	

1/ Maximum and minimum downfield grades are limited by (1) requirements for drainage, (2) protection from erosion by storm runoff, and (3) the criteria for the irrigation method to be used.

A topographic survey is always helpful and is usually necessary in planning a farm irrigation system. Such surveys may vary from a few scattered shots to a precise grid-type survey. Any of the conventional methods of making this survey are satisfactory, but it is important to locate and map benchmarks and points of known horizontal position in order to reestablish both vertical and horizontal control on the ground.

Prior to leveling design, the farm irrigation system must be planned so that the location of field boundaries, irrigation water-supply system, drains, and field roads are known. The leveling plan for an individual field must provide for furnishing borrow to or for absorbing waste from these adjacent features. It must also provide for the proper ratio between excavation and embankment.

Before leveling, the field should be cleared of trash and vegetative material. In desert areas, sage and brush should be cleared, raked, and burned. On cultivated lands, mowing and raking or burning will usually suffice. Crop ridges should be eliminated by disking or smoothing. The grass on sod lands should be mowed and raked, but the vegetation should not be plowed under immediately prior to leveling. Any operation that leaves the surface in a loosened condition makes it difficult to grade to an exact elevation.

Surveys

Planning Surveys.

A topographic survey often is needed to provide a basis for planning the farm irrigation system. For the layout of contour benches, a survey showing considerable detail is essential. A topographic survey may be made by any of the conventional methods; plane table, transit survey, field cross section, or if construction is to be done immediately, the grid system which will be utilized for construction can be used.

Design and Construction Surveys.

The proper field arrangement and the farm water distribution and drainage system must be planned before the field leveling can be designed. An entire field should be designed and leveled as a unit.

The area should be first cleared of vegetation and the surface prepared for construction. A grid system is usually used to provide both horizontal and vertical control and each grid point is staked. Half or full lath are commonly used for staking. Double right-angle prisms are often useful in staking the grid. The stakes remain in the field and after the leveling job has been designed, are marked to serve for construction stakes. Since they cannot remain in a cultivated field for long, the staking and design is usually done immediately prior to construction.

The usual grid spacing is 100 feet in each direction, but other spacings as 50 x 50, 66 x 66, 50 x 100, 75 x 100, etc., are sometimes found useful. Inexperienced earthmoving operators often have difficulty in carrying elevation 100 feet between stakes and sometimes request a closer spacing. However, a 50 x 50 grid requires four times as many stakes to set, shoot, plot, compute and mark as a 100 x 100-foot-grid, and so the wider spacing should be used where possible.

Many times ridges or swales will be found which fall between grid corners. When this occurs, additional stakes should be set on the highs or lows. These stakes are located in the grid with markings as (E+72) (7+00) and so are often referred to as "plus stakes".

After all points have been staked, levels are run to determine the ground elevation of each. Normally, ground elevations are determined to the nearest tenth foot, but may be taken to the nearest 0.05 foot in level areas or where other conditions make additional refinement helpful. Bench marks are established to the nearest hundredth foot and they also are often used as points of horizontal control. The location and the elevation of the water source is determined and any structures that might affect the drainage system are located and the controlling elevations determined. Any existing pipelines, drains, power lines, structures, roads or other important physical features are similarly located and tied into the grid.

Figure 12-1 shows a grid survey for leveling a 40-acre field using a 100 x 100-foot spacing. For convenience in identification, each east-west line of stakes was lettered and each north-south line was numbered. There are many methods of establishing a grid system on a field but in this case, Line 7 was first established at right angles to the south edge of the field and point A-7 placed one-half grid interval (50 feet) north of the fence line. Lines F and G were then established at right angles to Line 7 and their points chained and staked. Line 8 was then measured and staked parallel to Line 7. The adjacent Lines 7 and 8 were arbitrarily selected since they are near the center of the field.

At this stage, there were two rows of stakes in both directions across the field. Since the work was carefully done, the remaining stakes were placed by eye with sufficient accuracy. Thus, E-6 was placed in line with F-6 and G-6 and E-7 and E-8; E-5 with F-5 and G-5 and E-6, E-7 and E-8; etc.

Elevations of all points were then determined and plotted as shown in figure 12-1.

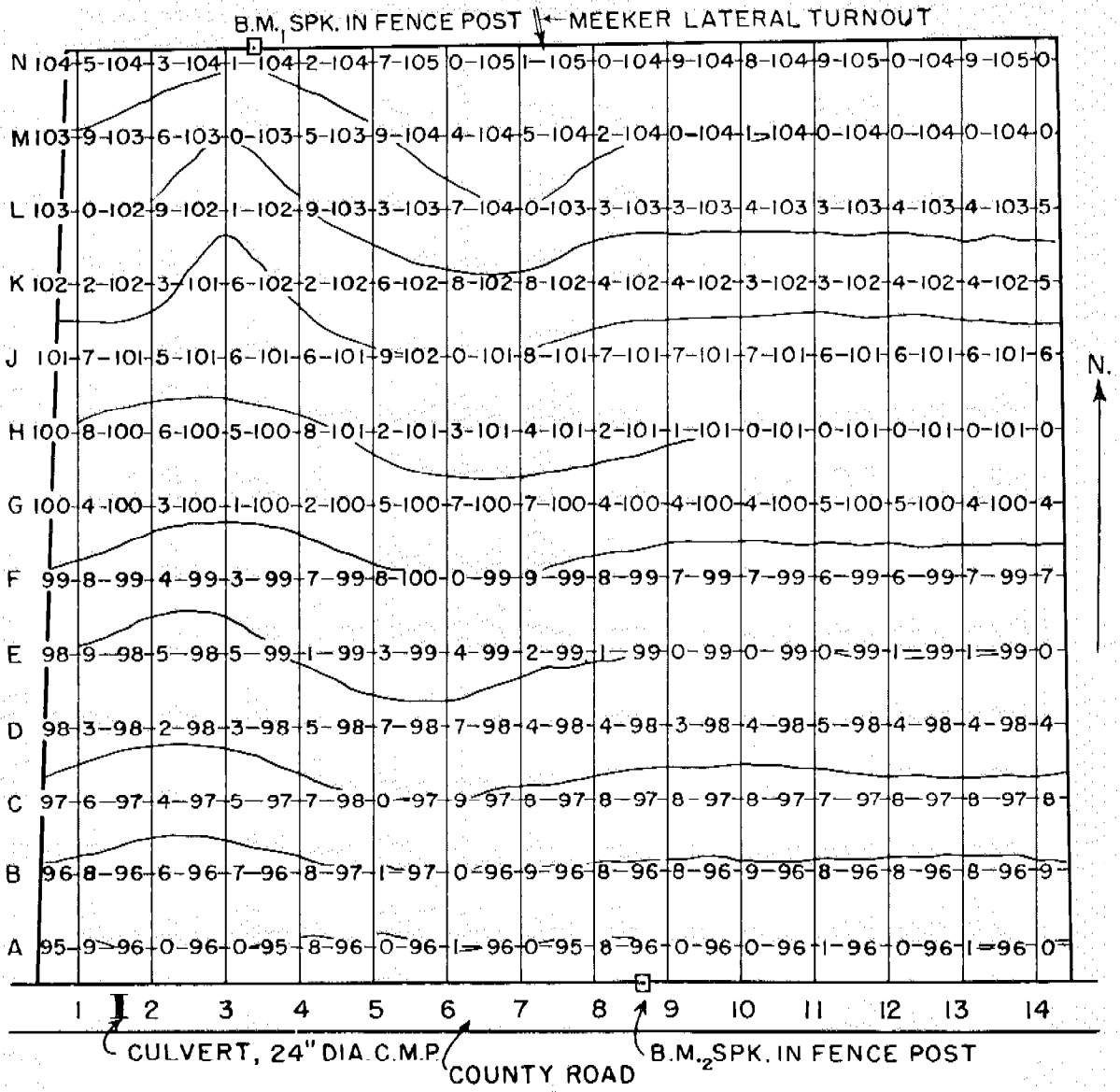


Figure 12-1.--Grid map for land leveling.

Land-Leveling Design Methods

General.
There are four basic methods and a great many variations of each method of land-leveling design in common use. These basic methods are:

1. The plane method.
2. The profile method.
3. The plan-inspection method.
4. The contour-adjustment method.

Each of these has some advantages and disadvantages, but when intelligently used, all will provide satisfactory results.

The Plane Method.

The plane method is so called because the resulting land surface has a uniform downfield slope and a uniform cross slope. Thus, a true plane surface results. It is a very useful method for developing Class A_1, A_2, and B_1 surface relief and is widely used.

The centroid of the area is first found, and a plane is passed through that point at an elevation equal to the average elevation of the field. When this is done, regardless of the slope of the plane, the volume of excavation equals the volume of fill. Since, as will be discussed later, more excavation than fill is necessary, the plane is lowered sufficiently to provide a proper balance.

The procedure for the design of land leveling by the plane method follows:

Subdivide the field into subareas.—The topography of many fields is such that they cannot be economically leveled to a single plane. Here, divide the field into parts, each of which can be developed to a plane surface. In making these subdivisions, keep in mind that the quality of the leveling job may be inadequate if the subareas do not match with the proposed ditch or water-supply locations. A study of the irrigation plan, the topographic map, and down-field profiles will assist the engineer in properly locating the subdivision boundaries.

Figure 12-2 is an example of a field that has been broken into three subareas for leveling. Here, the profiles and topographic map were both used as a guide. Each subarea is then considered as a separate field except that the common boundaries of the subareas are integrated into the design of the adjacent subarea.

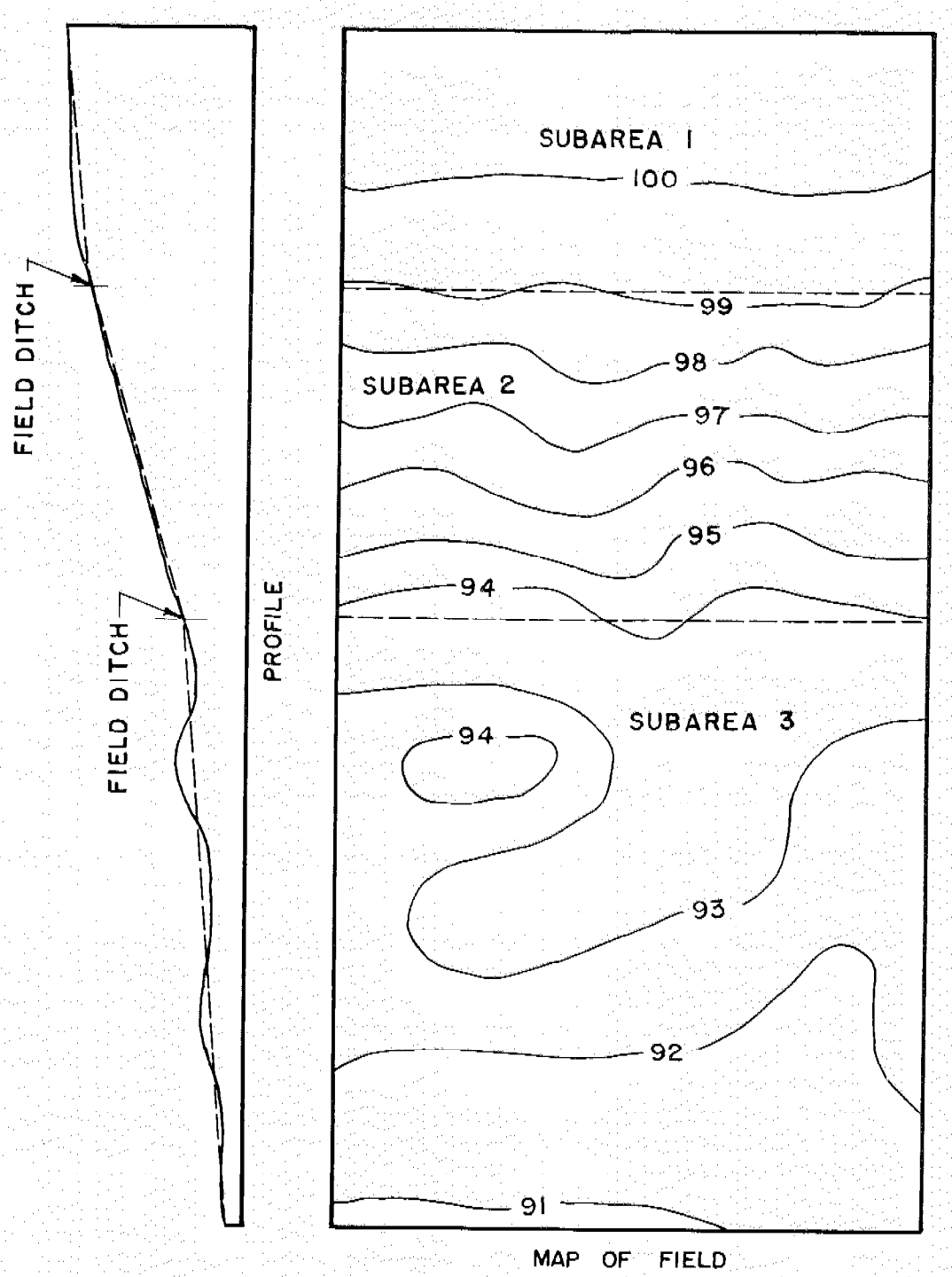


Figure 12-2.--Field subdivision for leveling.

Locate the centroid.—The centroid of a rectangular field is located at the intersection of its diagonals. The centroid of a triangular field is located at the intersection of lines drawn from its corners to the midpoints of the opposite sides.

Irregular fields may be divided into triangles and rectangles or into rectangles alone, and the distance to the centroid of the field from any line of reference is equal to the sum of the products obtained by multiplying the area of each part times the distance from the line of reference to its centroid, divided by the area of the entire field. By computing the distance to the centroid from [redacted] points of the centroid can be determined.

The centroid can also be located with sufficient accuracy by assuming that each stake (ignoring "plus stakes") in the field represents the same area. Figure 12-3 shows how the centroid can be located in this manner.

Assuming a line of reference 100 feet south of line A, the number of stakes in each line multiplied by the distance (in stations) from the reference line is:

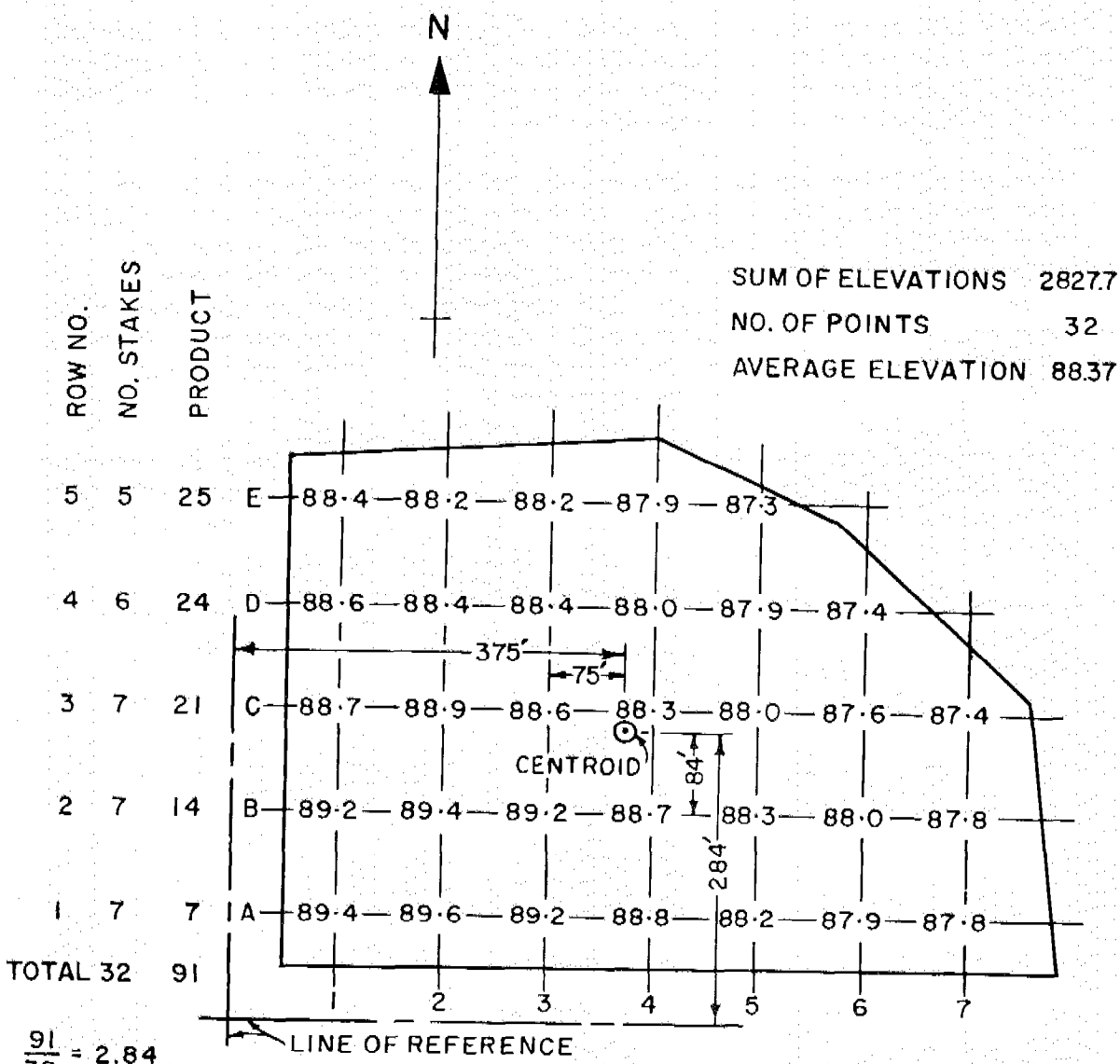
Line	Distance	No. of stakes	Product
E	5 stations	5	25
D	4	6	24
C	3	7	21
B	2	7	14
A	1	7	7
	Total	32	91

The distance of the centroid from the reference line is then found by dividing the sum of the products by the total number of stakes or

$$\frac{91}{32} = 2.84 \text{ stations or } 284 \text{ feet}$$

The centroid is, therefore, 284 feet from the reference line, or 84 feet north of line B.

Another line of reference was assumed to be 100 feet west of line 1 and the location of the centroid in an east-west direction computed the same way. With the two dimensions, the point was located at (B+84) and (3+75).



$\frac{91}{32} = 2.84$

ROW NO.	1	2	3	4	5	6	7	TOTAL
NO STAKES	5	5	5	5	5	4	3	32
PRODUCT	5	10	15	20	25	24	21	120

$\frac{120}{32} = 3.75$

Figure 12-3.--Location of the centroid of a field.

If the field is nearly rectangular, such as shown on figure 12-4, the centroid is located at the intersection of the diagonals or at coordinate (G+00) (7+50).

Determine the average elevation of the field.—Obtain the average elevation of the field by adding the elevations at all the grid corners in the field and dividing the sum by the number of points. Thus, for figure 12-3 the total of the 32 elevations on the grid corners is 2,827.7. The average elevation is

$$\frac{2827.7}{32} = 88.37$$

Any plane passing through the centroid at this elevation will produce equal volumes of cut and fill. Similarly, in the example on figure 12-4 the sum of the elevations of the 182 grid points on the field is 18,271.3 so the average elevation is

$$\frac{18,271.3}{182} = 100.39$$

Compute the slope of the plane of best fit.—Omit this computation if it is obvious from the topography that the plane of best fit will not meet leveling criteria.

With grid points at 100-foot centers, it can be shown that the slope of the plane of best fit on a rectangular area is expressed by the following

$$M_x = \frac{\sum (D_x H_y) - (A)(H)}{B}$$

$$M_y = \frac{\sum (D_y H_x) - (A)(H)}{B}$$

| | Y AXIS / X AXIS | | |

where D_x = distance in stations from the y axis.

D_y = distance in stations from the x axis.

H = sum of the elevations at all grid points.

H_x = sum of the elevations in an x direction along a grid line.

H_y = sum of the elevations in a y direction along a grid line.

M_x = slope of the plane in the x direction.

M_y = slope of the plane in the y direction.

A = constants taken from table 12-2.

B = constants taken from table 12-2.

If grid points are at other than 100-foot centers, the slopes M_x and M_y as determined by the preceding formula must be corrected as follows:

$$\text{Corrected } M_x = \frac{\text{Spacing of grid points in X direction}}{100} M_x$$

$$\text{Corrected } M_y = \frac{\text{Spacing of grid points in Y direction}}{100} M_y$$

An example of this calculation is shown in figure 12-4.

1. The sums of the elevations on each line were computed thus on the N line,

$$H_x = 104.5 + 104.3 + 104.1 + 104.2 + 104.7 + 105.0 + 105.1 + 105.0 + 104.9 + 104.8 + 104.9 + 105.0 + 104.9 + 105.0 = 1{,}466.4$$

Similarly on the 5 line.

$$H_y = 104.7 + 103.9 + 103.3 + 102.6 + 101.9 + 101.2 + 100.5 + 99.8 + 99.3 + 98.7 + 98.0 + 97.1 + 96.0 = 1{,}307.0$$

2. The value of H was computed by adding all the values of H_x. This sum was 18,271.3. As a check, the values of H_y were added and the same total obtained.

3. The location of the x and y axes were assumed. In this problem the x axis was placed one station north of line N and the y axis was placed one station west of line 1.

4. Values of D_y and D_x were tabulated. Since the N line is one station from the x axis, the value of D_y for the N line is 1; similarly, D_y for the M is 2; etc.

5. The products of $(H_x D_y)$ and $(H_y D_x)$ for each line were computed and tabulated as shown.

Table 12-2.--Constants for determination of plane of best fit.

NUMBER OF STATIONS IN THE DIRECTION SLOPE OF BEST FIT IS BEING DETERMINED

NUMBER OF STATIONS TRANSVERSE TO THE DIRECTION SLOPE OF BEST FIT IS BEING DETERMINED	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	VALUES OF A																								
	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5
	VALUES OF B																								
1	0.5	2	5	10	17.5	28	42	60	82.5	110	143	182	227.5	280	340	408	484.5	570	665	770	885.5	1012	1150	1300	1462.5
2	1.0	4	10	20	35	56	84	120	165	220	286	364	455	560	680	816	969	1140	1330	1540	1771	2024	2300	2600	2925
3	1.5	6	15	30	52.5	84	126	180	247.5	330	429	546	682.5	840	1020	1224	1453.5	1710	1995	2310	2656.5	3036	3450	3900	4387.5
4	2.0	8	20	40	70	112	168	240	330	440	572	728	910	1120	1360	1632	1938	2280	2660	3080	3542	4048	4600	5200	5850
5	2.5	10	25	50	87.5	140	210	300	412.5	550	715	910	1137.5	1400	1700	2040	2422.5	2850	3325	3850	4427.5	5060	5750	6500	7312.5
6	3.0	12	30	60	105	168	252	360	495	660	858	1092	1365	1680	2040	2448	2907	3420	3990	4620	5313	6072	6900	7800	8775
7	3.5	14	35	70	122.5	196	294	420	577.5	770	1001	1274	1592.5	1960	2380	2856	3391.5	3990	4655	5390	6198.5	7084	8050	9100	10237.5
8	4.0	16	40	80	140	224	336	480	660	880	1144	1456	1820	2240	2720	3264	3876	4560	5320	6160	7084	8096	9200	10400	11700
9	4.5	18	45	90	157.5	252	378	540	742.5	990	1287	1638	2047.5	2520	3060	3672	4360.5	5130	5985	6930	7969.5	9108	10350	11700	13162.5
10	5.0	20	50	100	175	280	420	600	825	1100	1430	1820	2275	2800	3400	4080	4845	5700	6650	7700	8855	10120	11500	13000	14625
11	5.5	22	55	110	192.5	308	462	660	907.5	1210	1573	2002	2502.5	3080	3740	4488	5329.5	6270	7315	8470	9740.5	11132	12650	14300	16087.5
12	6.0	24	60	120	210	336	504	720	990	1320	1716	2184	2730	3360	4080	4896	5814	6840	7980	9240	10626	12144	13800	15600	17550
13	6.5	26	65	130	227.5	364	546	780	1072.5	1430	1859	2366	2957.5	3640	4420	5304	6298.5	7410	8645	10010	11511.5	13156	14950	16900	19012.5
14	7.0	28	70	140	245	392	588	840	1155	1540	2002	2548	3185	3920	4760	5712	6783	7980	9310	10780	12397	14168	16100	18200	20475
15	7.5	30	75	150	262.5	420	630	900	1237.5	1650	2145	2730	3412.5	4200	5100	6120	7267.5	8550	9975	11550	13282.5	15180	17250	19500	21937.5
16	8.0	32	80	160	280	448	672	960	1320	1760	2288	2912	3640	4480	5440	6528	7752	9120	10640	12320	14168	16192	18400	20800	23400
17	8.5	34	85	170	297.5	476	714	1020	1402.5	1870	2431	3094	3867.5	4760	5780	6936	8236.5	9690	11305	13090	15053.5	17204	19550	22100	24862.5
18	9.0	36	90	180	315	504	756	1080	1485	1980	2574	3276	4095	5040	6120	7344	8721	10260	11970	13860	15939	18216	20700	23400	26325
19	9.5	38	95	190	332.5	532	798	1140	1567.5	2090	2717	3458	4322.5	5320	6460	7752	9205.5	10830	12635	14630	16824.5	19228	21850	24700	27787.5
20	10.0	40	100	200	350	560	840	1200	1650	2200	2860	3640	4550	5600	6800	8160	9690	11400	13300	15400	17710	20240	23000	26000	29250
21	10.5	42	105	210	367.5	588	882	1260	1732.5	2310	3003	3822	4777.5	5880	7140	8568	10174.5	11970	13965	16170	18595.5	21252	24150	27300	30712.5
22	11.0	44	110	220	385	616	924	1320	1815	2420	3146	4004	5005	6160	7480	8976	10659	12540	14630	16940	19481	22264	25300	28600	32175
23	11.5	46	115	230	402.5	644	966	1380	1897.5	2530	3289	4186	5232.5	6440	7820	9384	11143.5	13110	15295	17710	20366.5	23276	26450	29900	33637.5
24	12.0	48	120	240	420	672	1008	1440	1980	2640	3432	4368	5460	6720	8160	9792	11628	13680	15960	18480	21252	24288	27600	31200	35100
25	12.5	50	125	250	437.5	700	1050	1500	2062.5	2750	3575	4550	5687.5	7000	8500	10200	12112.5	14250	16625	19250	22137.5	25300	28750	32500	36562.5
26	13.0	52	130	260	455	728	1092	1560	2145	2860	3718	4732	5915	7280	8840	10608	12597	14820	17290	20020	23023	26312	29900	33800	38025

6. The sum of the products (H_xD_y) were obtained; this value is $\sum (H_xD_y)$. $\sum (H_yD_x)$ was also computed.

7. Values of A and B were taken from table 12-2. Thus, for the slope in the direction of the y axis, the number of stations along the y axis is 13, and this value was found on the horizontal column at the top of the table. Directly below, A was found to be 7.0. Since the number of stations along the x axis is 14, going down the same column to a point opposite 14 on the left side, the value of B was found to be 2548. Similarly, for the slope in the direction of the x axis, A is found to be 7.5 and B equals 2957.5.

8. These figures are substituted in the equation, and

$$M_y = -0.706 \text{ percent}$$

$$M_x = 0.020 \text{ percent}$$

Note that M_y is negative. That means that the elevation of the plane reaches a lower elevation as the distance from the x axis increases. Since M_x is positive, the plane of best fit rises to the right. It also should be noted that since the units of distance (D_x and D_y) were in stations, the result is in feet per station or percent slope.

Determine the elevation of the plane at the centroid.—Any plane passing through the centroid at the average elevation as previously determined will produce equal volumes of excavation and embankment. However, as explained in more detail in Earthwork Balance, it is necessary to have a larger volume of cut than fill to obtain a balance. Attain this by lowering the whole field a few hundredths of a foot. This will increase the amount of excavation and reduce the fill required.

The field in figure 12-4 has an average elevation of 100.39. To provide extra excavation the whole field is lowered 0.04 foot or to elevation 100.35 at the centroid.

It often is desirable to provide for borrow from a field to construct farm roads or elevated ditches or to waste spoil from a drain on a field. In these instances, the elevation of the centroid may be further raised or lowered as computed by the following formula:

$$H = \frac{27V}{A}$$

where

H = the adjustment necessary in feet (Positive when earth is to be brought onto the fill and negative when earth is removed)

V = the volume of borrow or waste in cubic yards

A = the area of the field in square feet

Had it been necessary to borrow 600 cubic yards from the field on figure 12-4, the following computation would have been made:

A = Average length of field x average width of field
= 1,373 x 1,275 = 1,750,575 square feet.

$$H = \frac{27 \times 600}{1,750,575} = 0.01$$

Average elevation of field	100.39
Less shrinkage	-0.04
Less borrow	-0.01
Design elevation of centroid	100.34

Compute the elevation for each grid point.—With the elevation of the centroid known and the downfield grade and cross slope selected, compute the elevation of each grid point.

In figure 12-5 the same field shown in figure 12-1 and figure 12-4 has been designed for leveling to the plane of best fit without either borrow or waste.

The following is known:

Location of centroid	(G+00) (7+50)
Elevation of centroid	100.35
Downfield slope	-0.706 percent
Cross slope	+0.020 percent

The elevation of point (G+00) (8+00) is then

$$100.35 + 1/2\ (0.02) = 100.36$$

and the elevation of all other grid points on line G can be computed by adding or subtracting 0.02 for each grid point to the right or left respectively.

The elevations of line H can then be obtained by adding 0.706 foot to the proposed elevations on line G. Similarly, all of the elevations are determined.

Compute the cuts and fills.—The desired cut or fill can be computed from a comparison of the original and the proposed elevations. Although the proposed elevations are carried to hundredths of a foot, round the cuts or fills to the nearest tenth or half tenth.

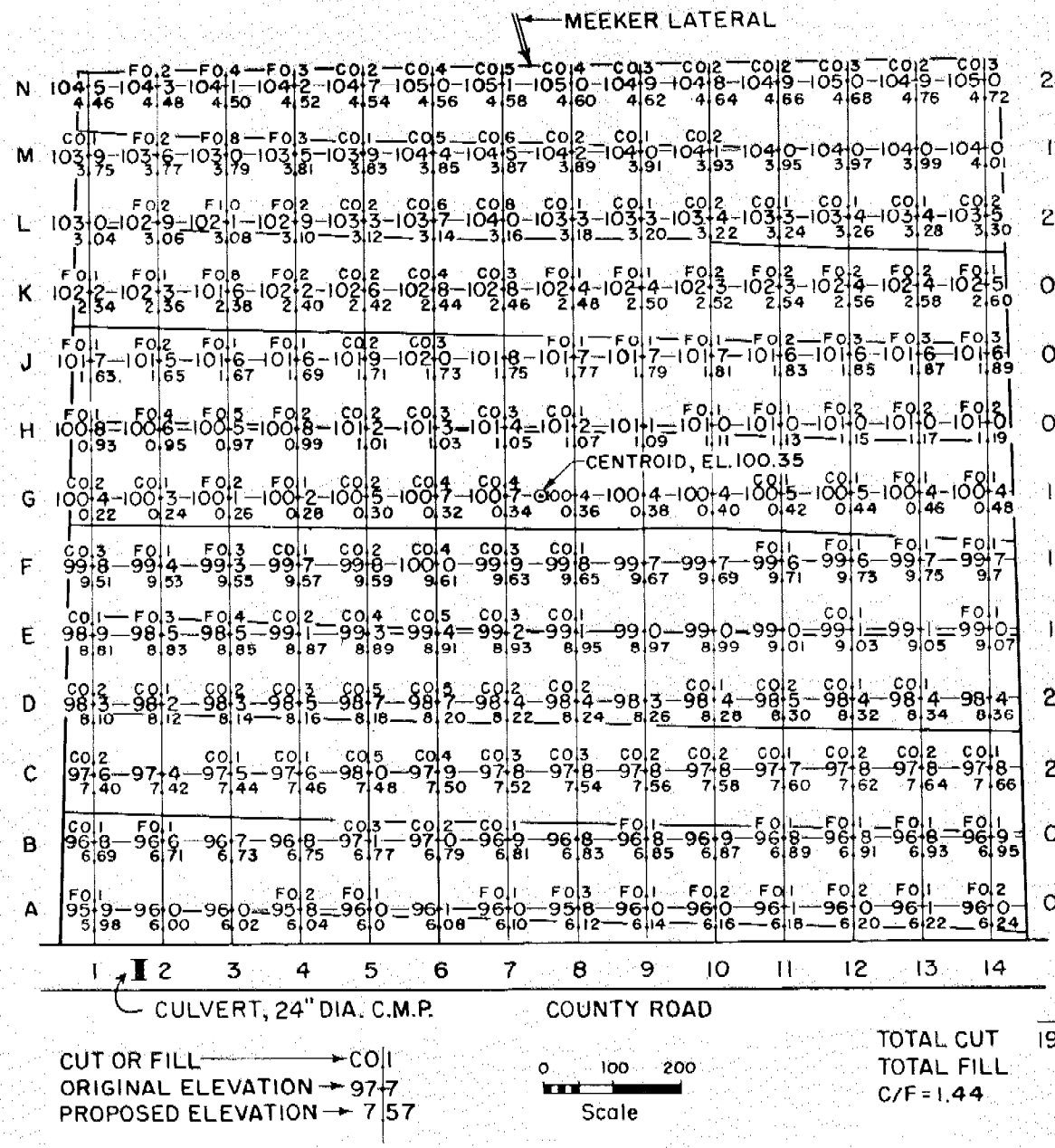


Figure 12-5.--The plane method of land leveling.

The calculations can be checked by determining the variation per stake. This variation should be less than 0.005 foot since the proposed elevations were rounded to the nearest hundredth foot. To do this, the cuts and fills on the computed points are separately summed and the difference between the two compared with the product of the shrinkage adjustment and the number of stakes. Thus

Sum of the cuts	=	20.6
Sum of the fills	=	14.1
Difference		6.5

No. of stakes = 13 x 14 = 182
Shrinkage adjustment = 182 x 0.04' = 7.28

Total variation = 7.28 - 6.5 = 0.78

Variation per stake = 0.78/182 = 0.0043

Since the variation per stake is less than 0.005, it is probable that the calculations are correct. Note that in the above example, the cuts and fills are <u>not</u> weighted for the area they represent as is done for the determination of the earthwork balance. Then check the earthwork balance as described in the section on Earthwork Calculation and make final adjustments to obtain the correct cut/fill ratio.

<u>The Profile Method</u>.
The profile method is so called because the designer works with profiles of the grid lines rather than with elevations as plotted on a map. It is especially well adapted to leveling design for very flat lands or land with undulating topography on which it is desired to develop a surface relief of Class B_2, C_1 or C_2.

There are many variations of the profile method, but essentially it consists of a trial and error method of adjusting grades on plotted profiles until the irrigation criteria are met and an earthwork balance is attained. Many workers find it relatively easy to select grades on a profile that will provide balanced cut and fill with reasonably short-haul distance and so the method is widely used.

Plot the profiles.--The profiles are commonly plotted in one direction and the individual profiles so located on the paper that the datum line for each profile is horizontally located in the correct position with the datum lines of adjacent profile. Figure 12.6 is an example of the same field shown in figure 12.1 plotted in this manner. It should be noted that the distance between the datum lines of line A and line B is identical with the distance between line 1 and line 2 on the A profile.

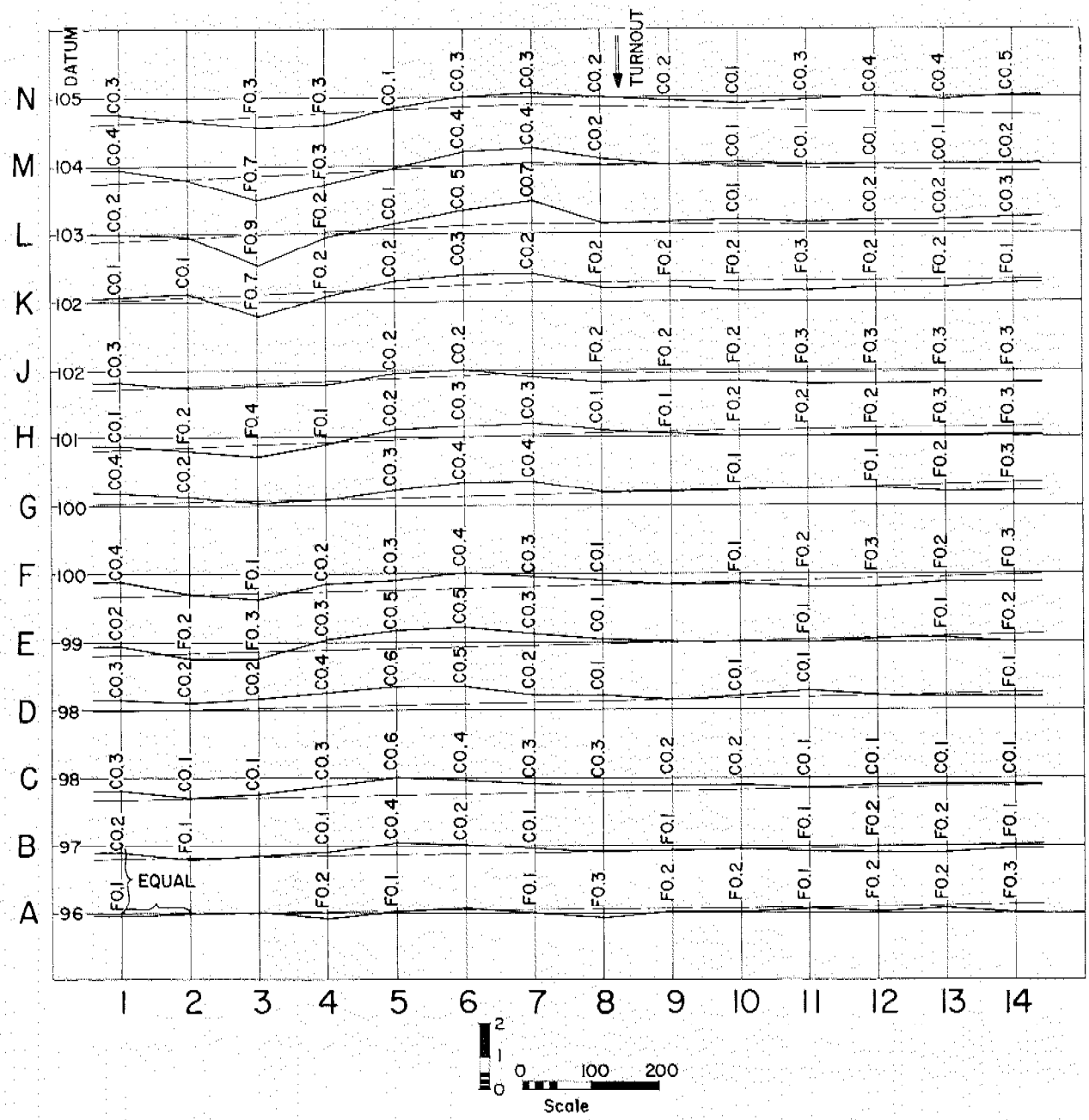


Figure 12-6.—The profile method of land leveling.

Figure 12.6 was plotted with the profiles across the slope. Some workers prefer to plot the profiles down the slope. Figure 12.7 is the same field with a down-field plot. Either method is satisfactory.

It sometimes is helpful to plot profiles in both directions, and it is quite common to plot at least a few key profiles in the opposite direction from the regular plot. These profiles often are drawn on the same sheet directly over but at right angles to the principal plot.

Another variation of plotting is the "two way plot" as shown on figure 12.8. The advantage of this method is that it provides a three-dimensional picture of the land surface, which is sometimes useful to those who are infrequently called upon for land-leveling design. In this method of plotting, the datum elevation is below the lowest elevation of the field, and each point is plotted both above the datum and to the right of the point of reference. All of the diagonals are 45 degrees. The "two way plot" cannot conveniently be used on fields with considerable differences in elevation.

Establish trial gradelines.—Trial gradelines are established on each profile based on the irrigation plan and the leveling criteria. On figures 12.6 and 12.7 it was decided to carry ditches to both the left and right from the turnout and to supply a cross ditch on the G line by carrying the water down the right side of the field. The water surface at the turnout is El. 105.5, and the field at that point should be at least 0.5 foot lower. Because of drainage requirements, it was further decided that the A line should have a slight grade downward to the left. Drainage criteria for the area should be consulted to determine the maximum and minimum allowable grades for surface drains.

As an example, in figure 12.6, trial gradelines were first placed on the control lines, N, G, and A, and then a balance between cut and fill was approximated by eye by maintaining the proper ratio between the area of cut and the area of fill.

Trial gradelines were then plotted on the other profiles. A smooth transition in cross slope was maintained by making the rate of change of cross slope between profiles equal.

Examine the grades between profiles.—The profiles should then be examined as to the relative elevations of one to another. Do this by plotting the elevations of the trial gradelines in the opposite direction to the original plot; i.e., if the original plot was cross-field, plot the elevations from the trial gradelines down field or vice versa.

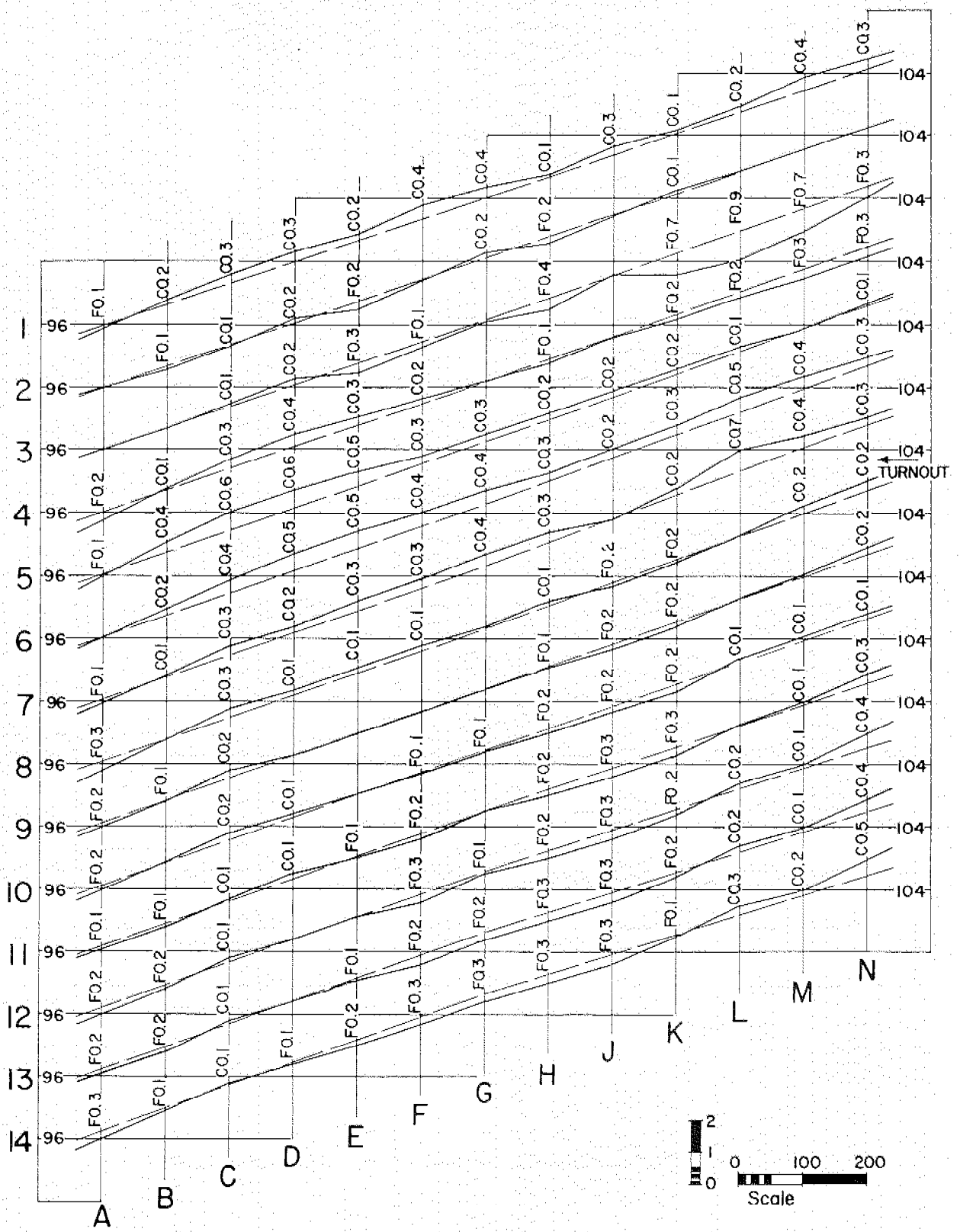


Figure 12-7.—The profile method of land leveling.

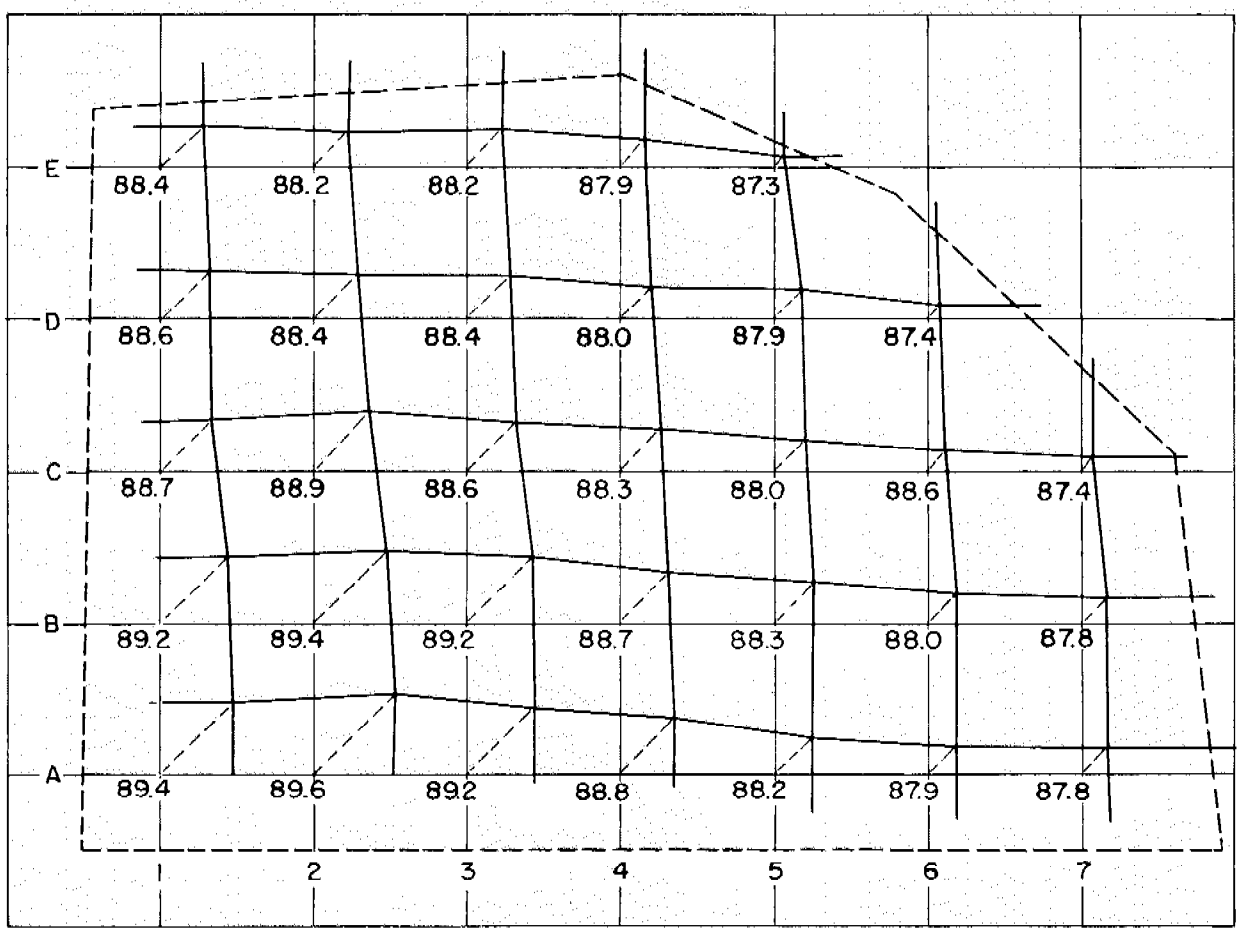


Figure 12-8.--Two-way method of plotting profiles.

Examine this cross profile and if the grade is not uniform to a point where it meets the criteria, draw a revised line. Transfer the elevations from this revised line back to the original profiles and move the gradelines upward or downward as required.

Some workers prefer to adjust the trial gradelines by inspection instead of plotting a cross profile. This is easily done but remember that the total amount the trial gradelines are moved upward must be equaled by the total amount the other lines are moved downward.

This latter procedure was used on figure 12-6. The difference in elevations between adjacent trial gradelines on line 7 was noted, and adjusted by [illegible] the difference [illegible] equal [illegible]. The final gradelines as shown were then drawn.

Regardless of the method, usually several trials are necessary before a satisfactory set of gradelines are developed.

Compute the cuts and fills.—From an inspection of the original and proposed profiles, the cut or fill at each grid point can be determined.

Compute the balance between cut and fill using the summation method as described in Earthwork Calculations. If the balance is not satisfactory, make further adjustment to the profiles until the proper balance is obtained.

The Plan-Inspection Method.

The plan-inspection method is one of the most widely used methods for developing lands to other than Class A or B surface relief. It is similar to the profile method in that it is a trial and error method.

Because of many factors which must be simultaneously considered, it requires considerable judgment to produce a satisfactory land surface without excessive cost. It is, however, widely used by experienced personnel in those areas where land leveling is a major practice. It is especially adapted for use on rolling lands or on fields where it is necessary to use warped surfaces.

In the plan inspection method, the survey data are plotted in the form shown in figure 12.1. Down-field and cross-slope limitations are determined, and by trial and error, proposed elevations are selected which will meet these limitations. In selecting elevations, the designer must simultaneously consider down-field slope, cross slope, earthwork balance, and haul distance.

Figure 12-9 is an example of the use of this method. In developing the design on this field, the following limitations were assumed:

1. Maximum cross slope is 0.1 foot per station and may be variable.
2. Maximum down-field slope is 1.0 foot per station.
3. Down-field slopes may be variable, but on convex slopes maximum grade may not exceed twice the minimum grade; on concave slopes maximum grades may not exceed 1.5 times the minimum grade; undulating slopes are not permissible.
4. The ratio between cut and fill shall be 1.5 ± 0.05.

Other considerations which affected the design were:

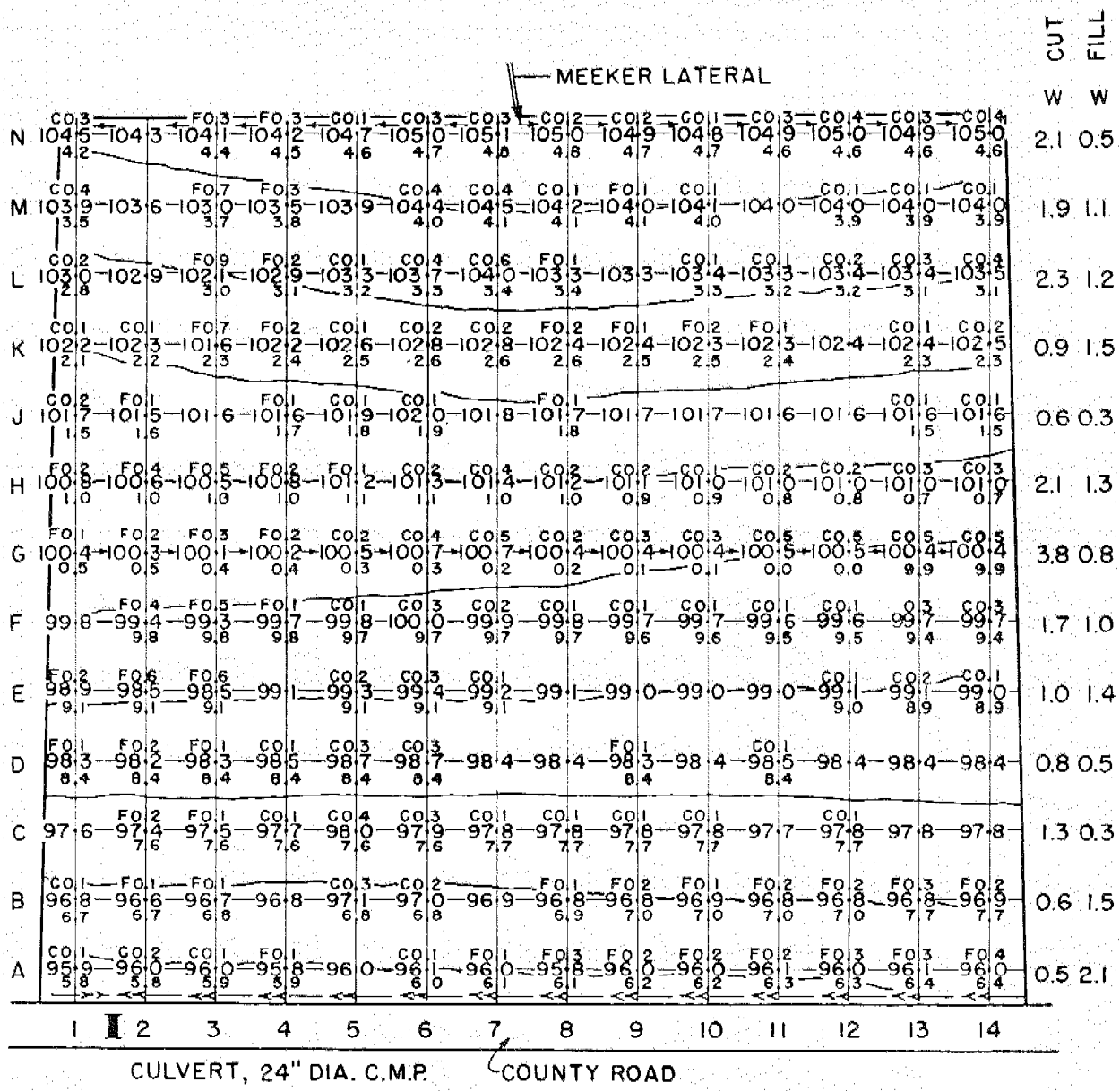
1. The length of run will be broken on the G line with an additional ditch.
2. Because of existing structures the supply lateral will be on the west side.
3. Surface drainage to the road culvert is desired without reverse flow in the drain.
4. The soil will permit a maximum excavation of 1.0 foot.

In developing this plan, elevations were first tentatively selected for the N line so that a ditch could be run in both directions from the turnout. The designer also examined the elevation of the water surface, which was given on figure 12-1 as 105.5, to be sure that the selected high point was not too high to receive service. Usually a minimum head of 0.5 foot is required for irrigation from ditches. Therefore the elevation of N-7 and N-8 could not exceed 105.0.

Tentative elevations were then assigned to the G line to be sure that the ditch to be located on that line would have the proper fall. Similarly, elevations were assigned to the A line to assure drainage.

With the N, G, and A lines serving as controls, elevations for intermediate points were selected by inspection keeping the design criteria in mind. To assure an earthwork balance, a running total of the sum of the tenths cut and tenths fill on each line were carried on the right side of the sheet. Lines N, G, and A, as well as intermediate points, were adjusted upward or downward as necessary to provide an earthwork balance. The designer also considered the borrow that would be required to build a permanent farm lateral on the north end of the field and the excavation that would be produced by the drain on the south.

By trial and error, adjustments were made till the plan on figure 12-9 evolved. This plan satisfies all the established criteria. The surface relief as developed is Class C_1.



EARTHWORK	EXCAVATION	FILL
LATERAL		262
LEVELING	6,690	4,519
DRAIN	407	
TOTAL	7,097	4,841
	C/F = 1.47	

TOTAL CUT = 19.5
TOTAL FILL = 13.5
C/F = 1.44

Figure 12-9.--The plan-inspection method of land leveling.

The Contour-Adjustment Method.
Basically, the contour-adjustment method of land leveling consists of a trial and error adjustment of the contour lines on a plan map. Cuts and fills are then determined by a comparison of the original and proposed contours.

The contour-adjustment method is a convenient method to use on fields where the cross slope can be made uniform across the field. It is especially adapted to those conditions when the leveling is accomplished over a period of time and when stakes cannot be maintained in the field.

It is also useful in leveling lands to be irrigated by contour methods, in leveling between terraces, or in removing extreme ridges or swales from steep lands which are being irrigated by the contour-ditch method.

The contour-adjustment method demands considerable judgment on the part of the designer to keep earth volumes and haul to a minimum. Like the profile method and plan-inspection method, success in its use is dependent upon the ability of the designer to recognize the relative importance of all the factors involved and to select a solution which satisfies the criteria and requires the least earthwork.

A requirement of this system is an accurate contour map of the area to be leveled. This need not necessarily be made with a grid-type survey but adequate ties and bench marks must have been located so that any point on the map can be located in the field through either vertical or horizontal control.

Figure 12-10 is an example of this method of leveling. In this field, the following limitations were assumed:

1. The maximum cross slope is to be 0.3 foot per station.
2. Down-field slopes are to be "fairly uniform" as defined in table 12-1.
3. The soils are deep and cuts up to 2.0 feet are permissible.
4. The field is to be irrigated from field ditches.

In developing this plan, it was obvious that the direction of irrigation should be from north to south. It was also apparent that the use of the maximum allowable cross slope would permit design with minimum earthwork quantities.

The location of the water supply at the northeast corner of the field requires that fall be provided to the west for the irrigation ditch along the north edge of the field. To provide this, the contour lines on the upper edge of the field were run in a north westerly direction. Likewise since it was not planned to change the natural drainage outlet for the field, the contours were arranged along the south line to provide drainage to the outlet.

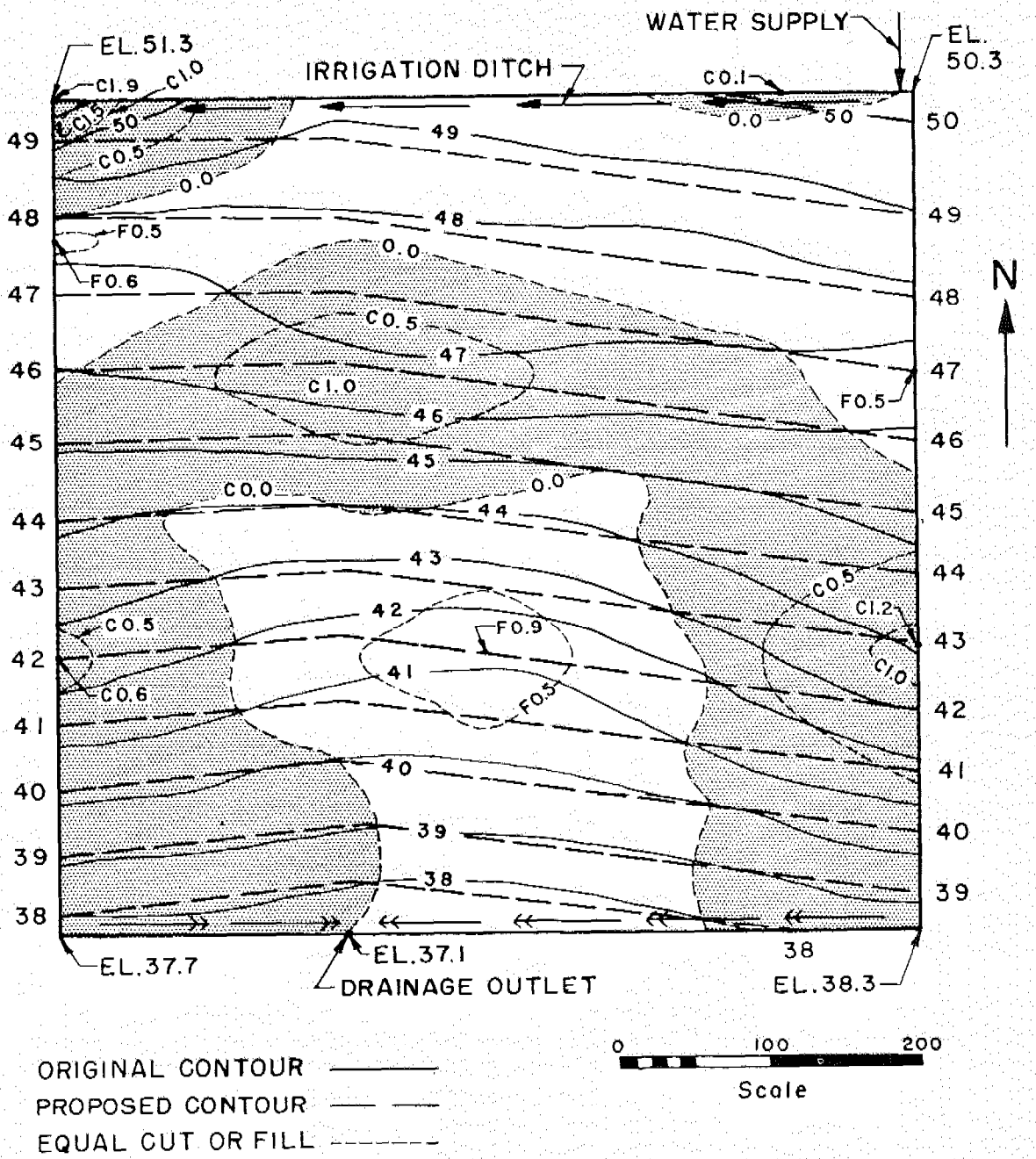


Figure 12-10.--The contour-adjustment method of land leveling.

Trial contours were then located. It was convenient to use an overlay on the original map for this purpose. In locating these trial contours, the area between the proposed and actual contours that represented excavation was made slightly greater than the area that represented fill. A sufficient number of contours were drawn to keep them less than 100 feet apart. It should be noted that on the example shown in figure 12-10 the final contours are straight lines, but on many fields, the finished contours may be curves.

Lines of equal cut or equal fill were then drawn through the intersections of the proposed and actual contours. The volumes of earthwork were computed by the horizontal-plane method later described in the section on Earthwork Calculations.

As expected, the first trial did not meet the established criteria nor have the proper ratio between excavation and fill. On a new overlay corrections were made, moving the proposed contours to the north to obtain additional, or to the south to reduce, the excavation. Care was also taken to keep the spacing between the proposed contours uniform or increasing in one direction only.

After several trials, the plan as shown on figure 12-10 evolved. It meets the limitations established. The surface relief as developed is Class C_1.

Since this design was accomplished without the benefit of a grid survey, it was necessary to utilize horizontal control to stake the field. Measurements were made along the sides of the field, locating the position of the proposed contours as scaled from the map. The points of deflection of the contour lines were similarily located by measuring from the field boundaries. From these points, the proposed contour lines were staked at 100-foot intervals. Levels were then run at these points and the cut or fill computed.

If the leveling is to be accomplished in progressive stages, permanent markers can be established along field boundaries and the proposed contour lines can be easily re-established at any time.

Some engineers prefer to use the contour-adjustment method even when a grid survey is available. Here, the procedure for obtaining the proposed finished surface is identical with that described but the elevation at each grid point is determined by interpolation between contours. The cut and fill at each grid point is determined by comparison between the original and proposed elevations, and earthwork volumes are computed by any convenient method.

When lands are steep and the surface is to be smoothed for irrigation by the contour-ditch or contour-furrow methods, the use of a grid survey and the contour-adjustment method is convenient. Irregularities in the contours can be smoothed on the map and the proposed elevations of the grid points determined by interpolation between contours. The summation method of computing earthwork volumes is commonly used since higher precision is seldom warranted.

Earthwork Calculations

Earthwork Volumes.
The exact method of computing the volume of earthwork in land leveling makes use of the prismoidal formula

$$V = L/6\ (A_1 + 4\ A_m + A_2)$$

Where

V = Volume in cubic feet.

L = Perpendicular distance between end planes in feet.

A_1 = Area of one end plane in square feet.

A_2 = Area of other end plane in square feet.

A_m = Area in middle section parallel to end planes in square feet.

The use of this formula is laborious, and approximate methods are commonly used.

The four-point method.—The four-point method is based on the formula

$$V_c = \frac{L^2}{108}\left(\frac{H_c^2}{H_c + H_f}\right) \quad \text{and}$$

$$V_f = \frac{L^2}{108}\left(\frac{H_f^2}{H_c + H_f}\right)$$

Where V_c = Volume of cut in cubic yards.

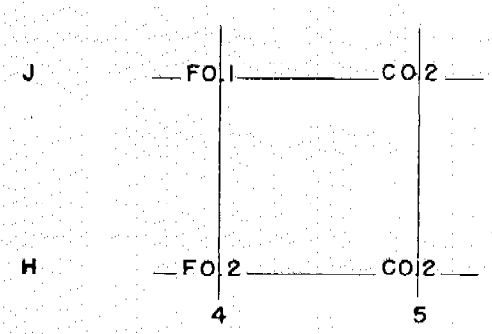
V_f = Volume of fill in cubic yards.

L = Grid spacing in feet.

H_c = Sum of cuts on four corners of a grid square in feet.

H_f = Sum of fills on four corners of a grid square in feet.

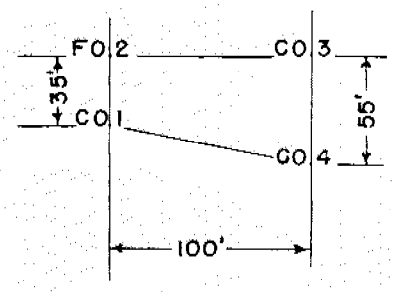
Using the formula, the volume of cut and fill in each grid square can be ascertained and the totals for the field obtained. Table 12-3 provides a rapid method for determining the excavation and fill in a 100-foot grid square. Let us examine the following grid:



The sum of the cuts are 0.4 and the sum of the fills are 0.3 Since the square is 100 feet to a side, the volume of earthwork as given by table 12-3 is

Excavation	21.2 cubic yards
Fill	11.9 cubic yards

The following methods have been found satisfactory for computing the volumes in other than square grids. For grids with four corners as



$$\text{Area grid} = \frac{35 + 55}{2} \times 100 = 4{,}500 \text{ square feet.}$$

Area in 100 x 100 grid = 10,000 square feet.

From table 12-3 for a 100 x 100 grid,

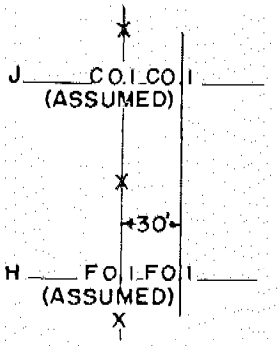
Cut = 59.3 cubic yards and fill = 3.7 cubic yards.

For the reduced grid

$$\text{Excavation} = 59.3 \times \frac{4{,}500}{10{,}000} = 26.7 \text{ cubic yards.}$$

$$\text{Fill} = 3.7 \times \frac{4{,}500}{10{,}000} = 1.7 \text{ cubic yards}$$

Correct use of the four-point method requires that the cut or fill be known at the outside edges of the field. In practice, however, stakes are seldom placed in the fence lines and usually it is satisfactory to assume that the cut in the fence line is identical with that of the nearest stake. Where abnormal conditions exist, plus stakes should be used. For the grid (0+30-1) (H-J) on figure 12-5, the following calculation was made:



Area in grid = 30 x 100 = 3,000 square feet.

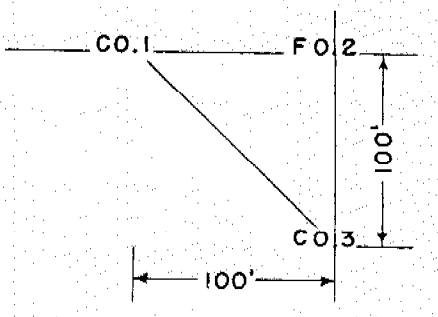
From table 12-3

C = 9.3 cubic yards.
F = 9.3 cubic yards.

Corrected = $\frac{3,000}{10,000}$ x 9.3 = 2.8 cubic yards

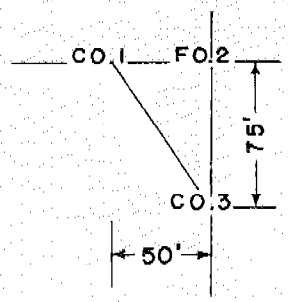
C = 2.8
F = 2.8

For a triangular area the sum of the three corners can be taken and the values in the table reduced to two-thirds. Thus,



Sum of cuts = 0.4
Sum of fills = 0.2
From table 12-3, C = 24.7 and F = 6.2
Excavation = 2/3 x 24.7 = 16.5 cubic yards
Fill = 2/3 x 6.2 = 4.1 cubic yards.

When triangular areas not 100 feet on each side are encountered, the volumes may be determined by further reducing the tabular values in proportion to the product of the length of the sides



Sum of cuts = 0.4
Sum of fills = 0.2

$$\text{Excavation} = \frac{50 \times 75}{100 \times 100} \times 2/3 \times 24.7 = 6.2 \text{ cubic yards}$$

$$\text{Fill} = \frac{50 \times 75}{100 \times 100} \times 2/3 \times 6/2 = 1.5 \text{ cubic yards}$$

The four-point method is rapid and gives an accuracy comparable to the accuracy of the original survey.

The end-area method.—The end-area method is based on the formula

$$V = \frac{L\ (A_1 + A_2)}{54}$$

Where

V = Volume of cut (or fill) in cubic yards.

L = Distance between end areas in feet.

A_1 = Area of cut (or fill) at one end in square feet.

A_2 = Area of cut (or fill) at other end in square feet.

The total areas (end area) of cut and of fill for each line in one direction, (i.e., A, B, C. D, etc., or 1, 2, 3, 4, etc.) are computed from the profile or taken directly from the plan. Thus, for the field shown in figure 12-5.

		Excavation			Fill		
Line	L	End area	Sum end area	Product	End area	Sum end area	Product
		Sq. Ft.	Sq. Ft.	Cu. Ft.	Sq. Ft.	Sq. Ft.	Cu. Ft.
N+25		288			84		
	25		576	14,400		168	4,200
N		288			84		
	100		458	45,800		207	20,700
N		170			123		
	100		411	41,100		258	25,800
L		241			135		
	100		322	32,200		352	35,200
K		81			217		
	100		132	13,200		396	39,600
J		51			179		
	100		136	13,600		370	37,000
H		85			191		
	100		223	22,300		231	23,100
G		138			40		
	100		267	26,700		112	11,200
F		129			72		
	100		288	28,800		140	14,000
E		159			68		
	100		427	42,700		68	6,800
D		268			0		
	100		557	55,700		0	0
C		289			0		
	100		356	35,600		57	5,700
B		67			57		
	100		67	6,700		227	22,700
A		0			170		
	50		0	0		340	17,000
A-50		0			170		
Total				378,800			263,000

$$\text{Excavation} = \frac{378,800}{54} = 7,015 \text{ cubic yards}$$

$$\text{Fill} = \frac{263,000}{54} = 4,870 \text{ cubic yards}$$

$$c/f = 1.49$$

The horizontal-plane method.—The horizontal-plane method is the end area method adapted to land areas instead of areas from cross sections. It is especially adapted for use when the contour-adjustment method of land leveling is utilized and on fields where there are heavy cuts and fills. It is based on the formula

$$V = \frac{H\,(A_1 + A_2)}{54}$$

Where

V = Volume of cut (or fill) between areas in cubic yards.

A_1 = Area of cut (or fill) C_1 in square feet.

A_2 = Area of cut (or fill) C_2 in square feet.

H = Difference between C_1 and C_2 in feet.

The accuracy of this method is best when values of H are small - i. e., 0.1 to 0.2 foot. H values as high as 0.5 foot are useful only for obtaining approximate quantities.

As shown on figure 12-10, lines of equal cut and equal fill were drawn on the map and the areas of each measured with a planimeter. Areas are expressed in square feet. The volume of excavation and fill on this field can then be computed as follows:

Cut or Fill Ft.	H Feet	Area Square Feet	Sum Area	Product	Volume Cu. Yards
			CUT		
0.0		189,100			
	0.5		220,000	110,000	2,037
.5		30,900			
	.5		33,000	16,500	306
1.0		2,100			
	.5		2,300	1,150	21
1.5		200			
	.4		200	80	2
1.9		0			
				Total	2,366
			FILL		
0.0		170,900			
	.5		180,400	90,200	1,670
.5		9,500			
	.4		9,500	3,800	70
.9		0			
				Total	1,740

Ratio cut to fill = 2,366/1,740 = 1.36

The summation method.--The summation method assumes that a given cut or fill on a stake represents an area midway to the next stake or on a 100-foot grid, 10,000 square feet. On this basis every foot of cut would involve a volume of

$$1/27\ (100 \times 100 \times 1.0) = 370 \text{ cubic yards}$$

This method is the least accurate of those shown. In those grid squares where cut changes to fill, the method gives values considerably greater than the true value. For that reason, it cannot be recommended for use except to obtain quick estimates of earthwork balance.

In using this method, the sum of all the cuts or fills in feet is determined and the total multiplied by 370 to obtain the yardage. If the "tenths" of cut or fill are added, the total is multiplied by 37.0. Points on the edge of a field are discounted in proportion to the area they represent. For example, the K line on figure 12-5 could be totaled as follows:

$$\Sigma C = 0.2 + 0.4 + 0.3 = 0.9$$

$$\Sigma F = (0.8 \times 0.1) + 0.1 + 0.8 + 0.2 + 0.1 + 0.1 + 0.2 + 0.2 + 0.2 + 0.2 + (0.8 \times 0.1) = 2.26$$

The volumes of earthwork represented by the area 50 feet on either side of this line are:

Cut = 0.90 x 370 = 33.3 cubic yards
Fill = 2.26 x 370 = 836.2 cubic yards

In the field shown on figure 12-9 the total cuts in the field added up to 19.4 feet and the fills to 13.3 feet. This would give a volume of

Cut = 19.4 x 370 = 7,178 cubic yards
Fill = 13.3 x 370 = 4,921 cubic yards

Comparison of methods.--To give an idea of the relative accuracy of these methods of computing earthwork, the field in figure 12-11 was computed by several methods with the following results:

Method	Cut	Fill	C/F
Prismoidal	6,732.8	4,474.7	1.50
Four Point	6,737.0	4,477.3	1.50
End Area	7,015	4,870	1.44
Summation	7,256	5,051	1.44

A comparison was also made for figure 12-10. To obtain cut and fill quantities to serve as a basis for the four-point and summation methods, grid points were established on 100-foot intervals. The original and proposed elevation of each grid point was assumed by interpolation between the contour lines. The following results were obtained:

Method	Cut	Fill	C/F
Four Point	2020	1252	1.61
Horizontal Plane	2366	1740	1.36
Summation	2490	1702	1.46

Earthwork Balance.

In land-leveling design it is essential that sufficient excavation be provided to construct the designed fills. When there is just enough excavation to do this and neither borrow nor waste is required, the earthwork is said to be in balance.

When a cubic yard of earth as measured in its original condition is loosened by excavation, its volume increases. This increase is known as "swell". When this same earth is placed in a fill and compacted, its volume decreases. The decrease as referred to the original volume is known as "shrinkage". Different soil materials have different properties in this regard. Some of the reasons which have been advanced by various engineers for the apparent high shrinkage factor required for land leveling are:

1. The bulk of materials moved in land leveling are top soils with a high organic content and relatively low original volume weight.
2. The cut areas in the field are subjected to considerable compaction by the earth-moving equipment. Hence the yield from an area of cut is less than that calculated.
3. In California Agricultural Experiment Station Circular 438, Mr. James C. Marr states: ". . . level ground surfaces between grade stakes appear to dip in the middle. To the extent that operators of the grading equipment allow this optical illusion to influence their judgment, crowning between grade stakes will occur".

Shrinkage of soil is variously expressed. For example, if one cubic yard of excavation of common earth will make 0.80 cubic yard of fill, it may be stated:

$$\frac{\text{Cut}}{\text{Fill}} \text{ Ratio} = C/F = 1.0/0.80 = 1.25$$

or

$$\text{Shrinkage factor} = \frac{1.0 - 0.80}{0.80} = 0.25 \text{ or } 25 \text{ percent}$$

or

$$\%\text{ Cut to }\%\text{ fill} = \frac{1.0}{1.8} \text{ to } \frac{0.8}{1.8} = 0.55 \text{ to } 0.45 = 55\% \text{ to } 45\%$$

Perhaps the most common approach in balancing earthwork is to vary the volumes of excavation and fill until the C/F ratio approaches a value believed to be valid for the conditions encountered. Experience in an area usually furnishes the background for selecting a value which proves satisfactory. Shrinkage factors usually vary from 10 percent for heavy leveling on firm field surfaces to as high as 100 percent for leveling with very shallow cuts and fills. Generally, the factor will be between 15 and 60 percent.

It is quite difficult to obtain more earth from an area which has been left a few hundredths high, but it is relatively simple to spread excess dirt and not exceed construction tolerances. For this reason, most equipment operators would prefer that the design shrinkage factor be somewhat high. On the other hand, the use of a high factor by the designer results in a higher computed yardage of excavation, and if the leveling is done on a unit-price basis, will result in a higher cost to the landowner.

When the plane method of leveling is used, it is convenient to assume that the whole field surface will be lowered by a certain amount by the compaction from the earth-moving equipment. This lowering can range from as little as 0.02 or 0.03 foot for very compact soils to as high as 0.10 foot for very loose soils. In the example in figure 12.5, lowering the plane 0.04 foot provided a C/F ratio of about 1.5. Lowering an additional hundredth would raise the C/F ratio to about 1.7 and raising it a hundredth would give a C/F ratio of about 1.3. With experience in an area, the amount that the plane needs to be lowered can be estimated as accurately as the C/F ratio required, and often, calculations to determine the earthwork volumes are omitted.

Construction

General.
Cut and fill stakes for construction purposes must be established to guide the equipment operator. When a grid-type survey exists, mark the cuts or fills directly on the original grid stakes. When the contour-adjustment method of design is used, set stakes as described in the description of the method and mark with the required cut or fill.

Equipment.
Most leveling is accomplished with tractor-drawn loading type scraper equipment. Tractors used are both crawler or rubber-tired wheel type and vary in size from small farm tractors to the largest heavy construction units. The variety of scrapers used is equally great since they must be chosen to match the power unit. Some of the points to consider in deciding how to do the job are as follows:

1. The time allowed to accomplish the work

Land leveling must fit somewhere into the cropping sequence, and often the number of days that a field is open for such work is limited. Where the period is long, small equipment may be used, but when time is pressing, it is wise to select large earth-moving equipment that can do the job in a hurry. It is important that the time to do the work is not underestimated.

2. The skill of the operator

If the equipment operator has not had experience in land-leveling work, it probably is advantageous to utilize small equipment. The slow rate of construction progress allows him more time to size up his work and make decisions. Land leveling is essentially a "finish grading" operation, and many operators with considerable experience in rough grading are not trained to work to the close tolerances necessary.

3. The haul distance

When the earth is to be moved over a considerable distance, the time in moving becomes an important segment of the cycle time. For long hauls, rubber-tired units usually will be best. When this equipment is used, it must have adequate power to load the scraper or be supplemented with pusher equipment.

On occasional jobs, the use of blade graders or auto patrols will be found useful. This is especially true for work in bench leveling where ridges are to be thrown up. They are sometimes used for leveling the benches themselves but if the benches are wide enough that tractor and scraper units can maneuver, the latter will usually be the most efficient.

Construction Procedure.
There are probably as many methods of approaching a land-leveling job as there are equipment operators and the following procedure is suggested as an example of how a job might be done:

A map similar to that shown in figure 12.11 is convenient for studying the best approach. The north side of the area might be considered as a logical starting point. To keep the haul distance to a minimum, it is important to construct the fills from the nearest excavation available. Excavation north of the M line could first be worked out by moving the dirt from the west edge of the cut area into the adjacent fill area until it was complete and then by moving the balance of the cut south into the fill area between the K-L and 7-14 lines. As the excavation between the M-N lines was complete, the L-M area of cut could be opened and the fills in the L-M lane completed. Work progresses to the south completing each lane of cut before moving out. The fill areas can also be progressively finished toward the south side. Since the earthwork balances, the last of the earth from the B-C-D lanes will be required to complete the fills in the A-B-C lanes.

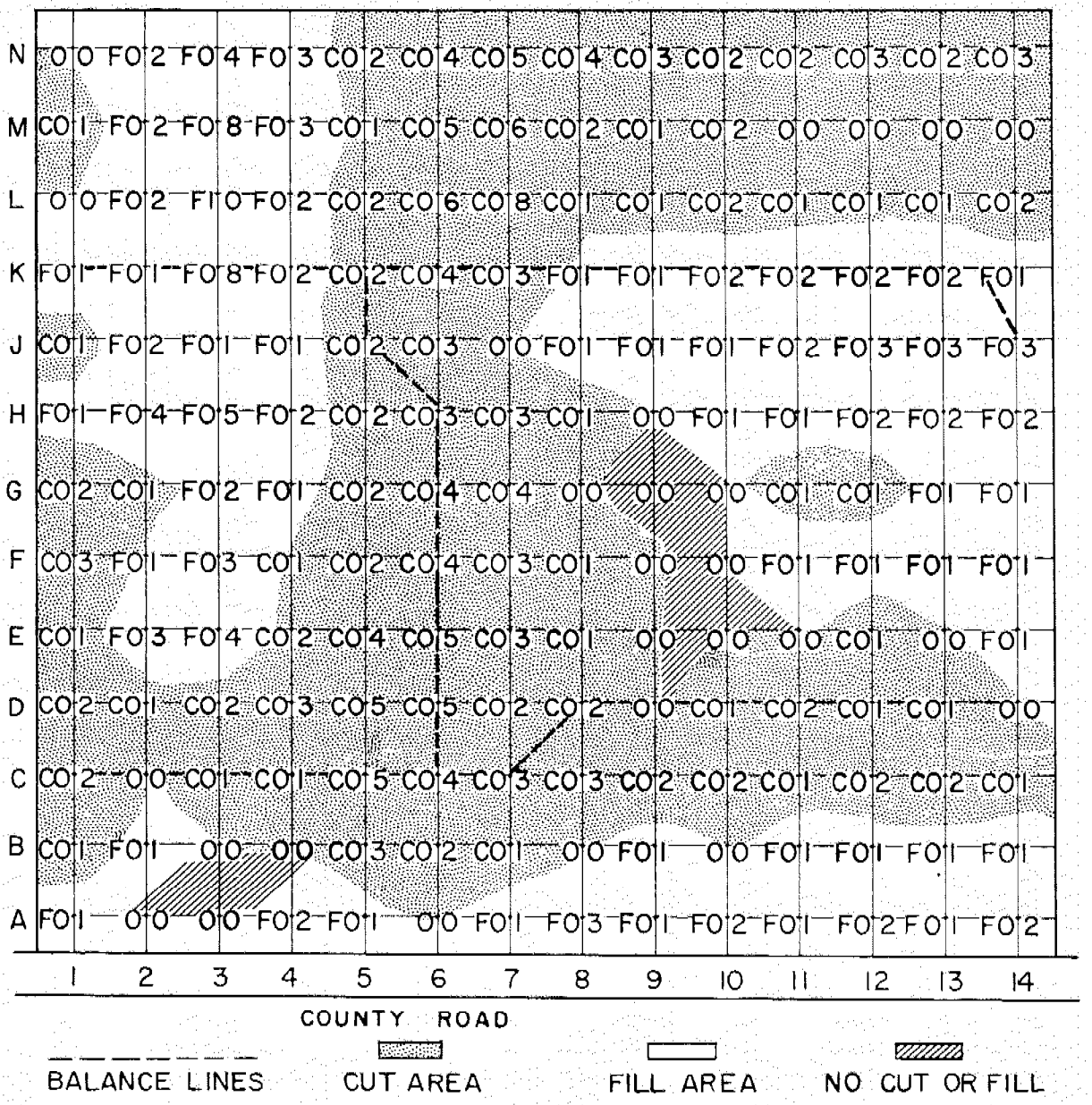


Figure 12-11.--Construction map for land leveling.

Some engineers prefer to make a detailed study of construction map and prepare balance areas in which there is just sufficient excavation to make the required fill. In figure 12-11, the field has been subdivided into four areas in which the earthwork balances. These can be further broken down into additional areas if one so desires. Each balance area is leveled as a unit insuring short-haul distances.

In performing these operations, do not disturb the grid stakes. In opening a lane, many operators prefer to first cut and fill a strip one scraper width wide adjacent to the stake line. After this is brought to the design elevation, work begins on the intermediate area. With this method it is easier to carry the grade by eye laterally across the lane. By working at a slight diagonal, the areas between stakes can be almost completely worked out until there remains only small "islands" around each grid stake. These are allowed to remain until the field has been checked.

When fills more than 0.5 foot are encountered, build them in layers not over 6 inches in depth to avoid excessive settling. In some areas it is common practice to provide extra fill height of approximately 10 percent to compensate for settlement.

When ridges are to be built as on the edges of contour benches, the volume of earth for the ridge should be available within a blade width of its finished location. Accomplish this by placing a small overfill on the edge of the bench. This extra fill should be one scraper width wide and one to three-tenths high depending upon the cross-sectional area of the dike. The blade can then crowd it into position. Another method is to leave a vertical bank between benches which is later sloped by throwing the dirt uphill and forming the dike.

Preservation of Topsoil.

Under some soil conditions it may be specified that the topsoil from an area must be stockpiled, the cuts overexcavated, and the topsoil replaced. The fill areas, too, must be stripped, the fills partly made with the materials available, and the topsoil replaced. Since this involves moving some earth twice, it is an expensive procedure and should be carefully justified.

When this operation is essential, first stockpile the topsoil from one lane on an area requiring little cut or fill. The cuts and fills in this lane should then be completed and the topsoil from the adjacent lane stripped and used for dressing the surface of the first lane. Then progressively across the field, move the topsoil to the adjacent lane as the leveling is completed until the last lane is dressed with the topsoil stockpiled from the first lane.

The "strip cut" method of land leveling is a modification which partially preserves the topsoil. This is described by M. E. Hoffman, United States Bureau of Reclamation of Minot, North Dakota.

> "The top six inches, or the plow depth, of soil normally contains most of the stubble residue, plant roots and humus materials. Difficulties in traction, loading and unloading operations are frequently encountered with this type of soil.
>
> These difficulties can be partially remedied by excavating alternate strips at double the designed cut depths thus facilitating capacity loading over shorter reaches.
>
> The 'strip excavated soils' consist of a mixture of topsoil and the more compact subsoil which can be unloaded more uniformly and leveled more readily.
>
> Leveling of the remaining alternate strips can be partially accomplished by routing empty scrapers over the edges of the cut banks. The balance of the leveling can be accomplished by diagonal operation of either a bulldozer or scrapers with the crowd gate in forward position."

Construction Tolerance.

Normally earthwork operations have a permissible tolerance of $\pm$ 0.1 foot. On flat slopes, however, it is usually necessary to make an additional restriction prohibiting reverse grades in the direction of irrigation. Normally it is impractical to accomplish a high finish with scraper equipment, and where possible the use of large land floats or planes are recommended to eliminate minor irregularities. The scraper work should be accomplished to the degree that two trips over with the float equipment will produce the desired finished surface.

Checking.

The final check must be made before the grid stakes are removed. On slopes exceeding 1 percent, it usually is adequate to check the cuts and fills at each stake with a hand level. On flatter slopes, use a level and ascertain elevations adjacent to each point. Grade between stakes must be uniform. Mark for correction the nonpermissible deviations from the prescribed grade.

When the field has been approved, the mounds and depressions left at the grid stakes are leveled to match the adjacent surface.

Finishing.
After the earth moving has been completed, it is advisable to plane the surface to remove minor irregularities. This is usually done by planing first at a 45-degree angle to the gridlines and again at right angles to the first operation.

Although a field may be leveled perfectly, sometimes after irrigation water is applied areas will settle unequally. Where deep furrow crops are grown, it may be advisable to irrigate by the furrow method for a year following leveling and delay the planing until after the initial settlement has taken place. Perennial crops should not be planted until settlement has taken place and corrections made.

Maintenance.
A leveled field requires maintenance to preserve its surface. Erosion from wind or water or improper use of farm plows and tillage equipment can seriously change its irrigating characteristics. Farm equipment such as two-way plows and tandem disks will eliminate dead furrows and ridges and so should be used. Smoothing with small farm floats should be frequently done. This practice should be regarded as a cultural practice--not a releveling operation.

Special Practices

Contour-Bench Leveling.
Contour-bench leveling is a method of preparing land for irrigation. The field is divided into a series of strips on the approximate contour, and each strip is leveled as an independent area. Thus a series of steps is formed down the slope. It provides a method of reducing grade on a field where excessive slope makes irrigation difficult or hazardous.

The advantages of contour-bench leveling are:

1. Irrigation water is easily controlled on the flat slopes, efficient irrigation methods can be used, and water-application efficiencies can be high.
2. Erosion from rainfall can be controlled. This permits soil-building processes that result in increased fertility and improved soil structure.
3. Since large stream sizes can be used and lengths of run can be comparatively long, labor in irrigating is lowered.
4. The flat slopes permit a more efficient use of both irrigation water and rainfall thereby reducing the quantity of irrigation water needed to meet plant requirements.

Disadvantages are:

1. Because the escarpment area between benches is too steep to farm, some area is lost to the production of the field crop. These areas can be seeded to perennial crops.
2. When the vertical drop between benches is over 18 inches, rodent control may be necessary to prevent washouts between benches.
3. The escarpment areas between benches present problems in maintenance and best utilization.
4. Waste irrigation water and runoff from rain accumulates high on the slope and must be conveyed to the lower edge of the farm.

Bench cross sections.—Selecting the proper cross section for contour benches is one of the most important phases of the planning. Figure 12.12 gives the shape normally used.

Determine first dimension W, the width of the farmable area. This width should be such that it will fit the farm equipment to be used. The least flexibility in farming is normally present with row crops and the width, W, should be in multiples of the width of the widest equipment anticipated. Unless farm roads are to be established at both ends of the benches, the width should be sufficient to allow round trips so that at the end of a tillage operation, the equipment is in position to move to an adjacent bench. The engineer should consider both the present and possible future farm equipment to be used in determining farmable width.

The relationship between W, T, and H may be expressed

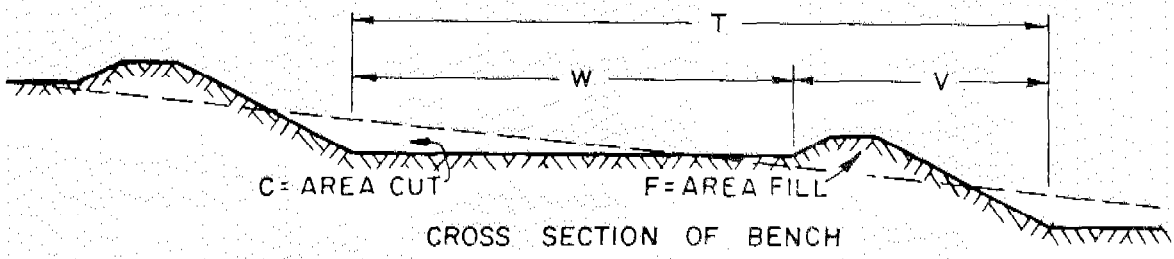
$$T = (W + B + 2hZ)\left(1 + \frac{SZ}{1 - SZ}\right)$$

and

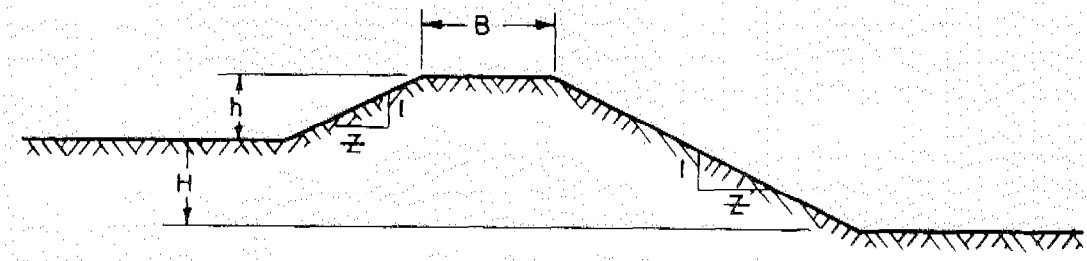
$$H = sT$$

where

T = Overall bench width in feet.
W = Width of farmable strip in feet.
B = Top width of dike in feet.
h = Height of dike in feet.
H = Vertical interval between benches in feet.
Z = Side slope of dike.
s = Slope of land in feet per foot.



CROSS SECTION OF BENCH



CROSS SECTION OF DIKE

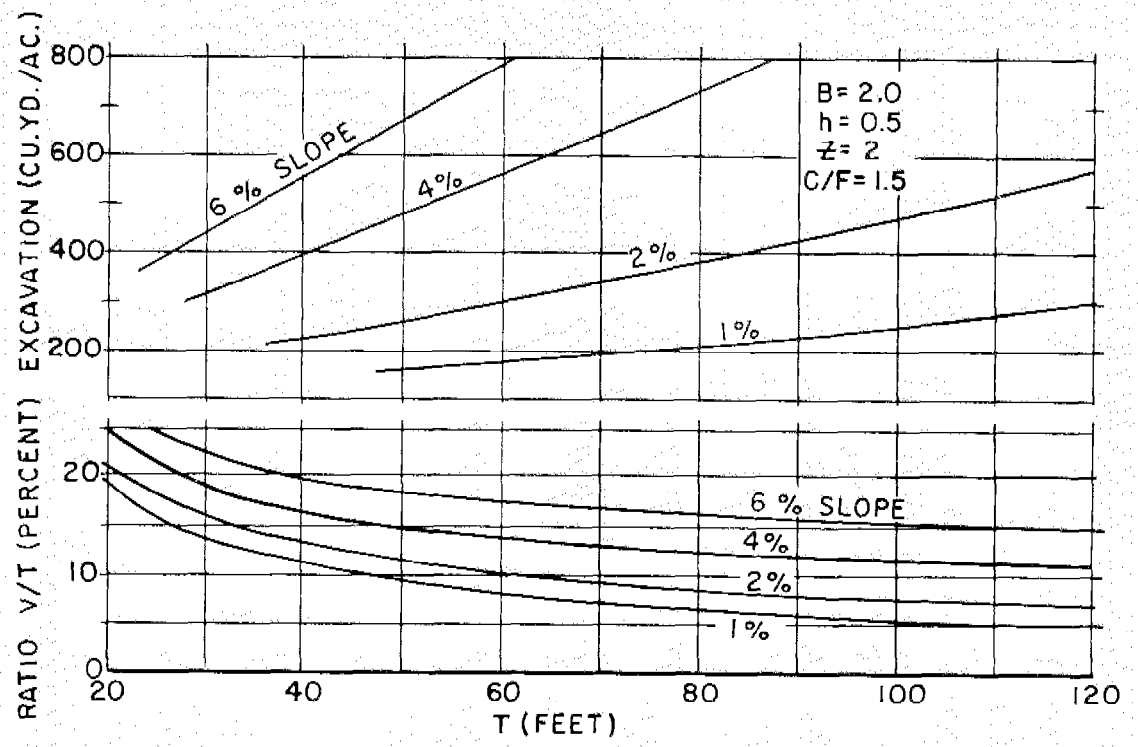


Figure 12-12.--Contour-bench relationships.

Another important consideration in selecting the bench spacing, T, is the area of land that will be utilized for the dike and escarpment areas. Depending upon crop and climate, this area may be nonproductive or of limited use. The relationship between the bench spacing, T, and the ratio V/T is shown on figure 12-12 for a typical dike cross section. Note that as the spacing, T, increases, the ratio V/T or the percent of land removed from production becomes less. Also note that as T increases, the volume of excavation required increases. The designer must select a spacing, T, which is a compromise between these two relationships.

The vertical interval between adjacent benches, H, must also be considered. On a given slope, as T or W increases, H also increases. As this dimension increases more than 1 foot, problems in maintaining the escarpment area increase rapidly. In only rare instances should H exceed 2 feet.

The height of the dike. h, should be sufficient to safely contain both the normal irrigation stream and storm runoff. Compute the depth of flows and provide a minimum freeboard of 0.2 foot above the maximum stage. On sandy soils or for pasture areas, increase the freeboard to 0.5 foot.

The side slopes, Z, should be selected with an eye to stability. 2 to 1 or 3 to 1 slopes are usual, but when stones are present in a field, the stones are often moved to the escarpment area and support a steeper slope.

The top width of the dike should be sufficient to prevent lowering of its height by trampling or by farm machinery. Usually the dimension B should be about equal to H, the drop between benches.

Bench location.—The location of the contour benches may be regarded as a part of the basic farm planning in which the field boundaries, irrigation water-supply system, drains, and field roads are located. For leveling, each bench is regarded as a separate field.

Since the earthwork involved is oftentimes great, lay out the benches to conform as closely to the original topography as farming operations and other considerations will permit. To make this layout, an accurate topographic map of the area under consideration is essential. It is necessary that this map have permanent points of reference for horizontal control located in the field since the benches will later need to be marked out using horizontal methods.

The need for a topographic map is lessened on flat, smooth slopes, and sometimes the bench location can be determined by inspection. It should be recognized, however, that the cost of a good topographic map is usually less than the cost of moving 15 cubic yards of earth per acre, and savings in earth volumes greatly in excess of this amount often result from intelligent use of a good map.

First separate the area to be developed into key areas, each having fairly uniform topographic features. In the field shown in figure 12-13, one key area might be considered to be the area between the 91 and 95 contours. Another is between the 88 and 90 contours.

Location of guidelines.—Guidelines should then be located which represent an average condition of each key area. This can be done by locating a line that represents the average shape of the contour lines and then computing the location of the guideline to the grade desired by offsets from the line representing the average of the contours.

In figure 12-13 random lines a, b, c, d, e, f, g, and h were drawn and the distance from a reference line to each contour within a key area was measured. The north fence line was arbitrarily picked to be the reference line. These measurements scaled as follows:

	Random line							
Contour	a	b	c	d	e	f	g	h
95	215	180	100	40	13	10	20	63
94	270	250	180	85	53	65	90	145
93	345	315	245	173	117	120	143	195
92	413	378	320	260	205	183	185	242
91	472	450	403	345	300	265	260	280
Average	343	315	250	181	138	129	140	185
90				425	390	355	330	330
89				495	463	433	413	413
88				635	550	505	475	475
Average				518	468	431	406	406

The average of the scaled distances as shown above represent the distance from the reference line to the average of the contours, and these latter lines can be plotted on the map.

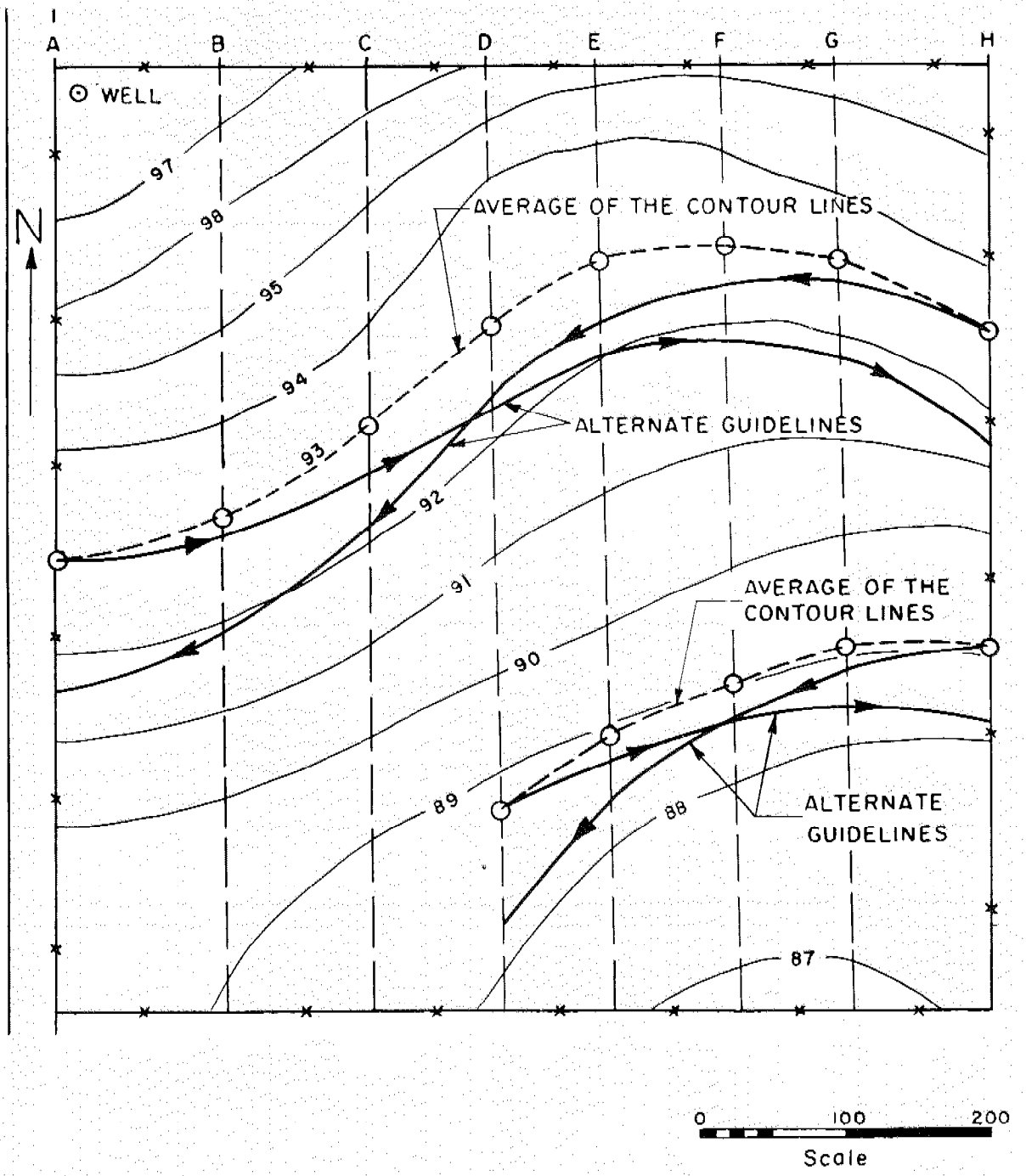


Figure 12-13.--Establishing guidelines for contour-bench leveling from contour map.

The average slope along the random lines in each key area should then be computed. Usually it is sufficiently accurate to determine this slope from the bottom edge to the top edge of the key area. The average slope is calculated by dividing the difference in elevation by the difference in distances from the reference line. For the field in figure 12-13 this becomes

	Random line							
Contour	a	b	c	d	e	f	g	h
95	215	180	100	40	13	10	20	63
91	472	450	403	345	300	265	260	280
Percent slope	1.56	1.48	1.32	1.31	1.39	1.57	1.67	1.84
90				425	390	355	330	330
88				635	550	505	475	475
Percent slope				0.95	1.25	1.33	1.38	1.38

Knowing the location of the line representing the average of the contours and the slope of the land, it is possible to determine the horizontal adjustment necessary to represent a guideline for any desired grade. For the problem in figure 12-13 it was desired that the benches should have a slope of 0.002. The following computations were made to determine the necessary horizontal adjustments assuming a grade first in one direction and then in the other.

Between contours 91 and 95								
Random line	a	b	c	d	e	f	g	h
Avg. slope percent	1.56	1.48	1.32	1.31	1.39	1.57	1.67	1.84
Station	0+00	1+20	2+30	3+30	4+20	5+00	5+80	6+95
Fall	0	0.24	0.46	0.66	0.84	1.00	1.16	1.39
Adjustment	0	16'	35'	50'	60'	64'	69'	76'
Station	7+30	6+10	4+80	3+70	2+80	1+90	1+10	0
Fall	1.46	1.22	0.96	0.74	0.58	0.38	0.22	0
Adjustment	94'	82'	73'	56'	42'	28'	13'	0

Between contours 88 and 90								
Random line	a	b	c	d	e	f	g	h
Slope percent				0.95	1.25	1.33	1.38	1.38
Station				0+00	0+90	1+80	2+60	3+60
Fall				0	0.18	0.36	0.52	0.72
Adjustment				0	14'	27'	38'	52'
Station				3+80	2+70	1+80	1+00	0
Fall				0.76	0.54	0.36	0.20	0
Adjustment				80'	43'	27'	14'	0'

An example of this calculation can be shown for the guideline falling to the east on the upper key area. Station 0+00 was considered to be at the intersection of the average to the contour line and random line a. By scaling, it was estimated that the stationing at the point where the guideline would cross random line b would be 1+20. Since the grade in the bench is to be 0.002, station 1+20 would be 0.24 foot below the average to the contour line. On line b, the average slope is 1.48 percent and the necessary adjustment (or the distance from the average to the contour line and the guideline) is

$$\frac{0.24 \times 100}{1.48} = 16 \text{ feet}$$

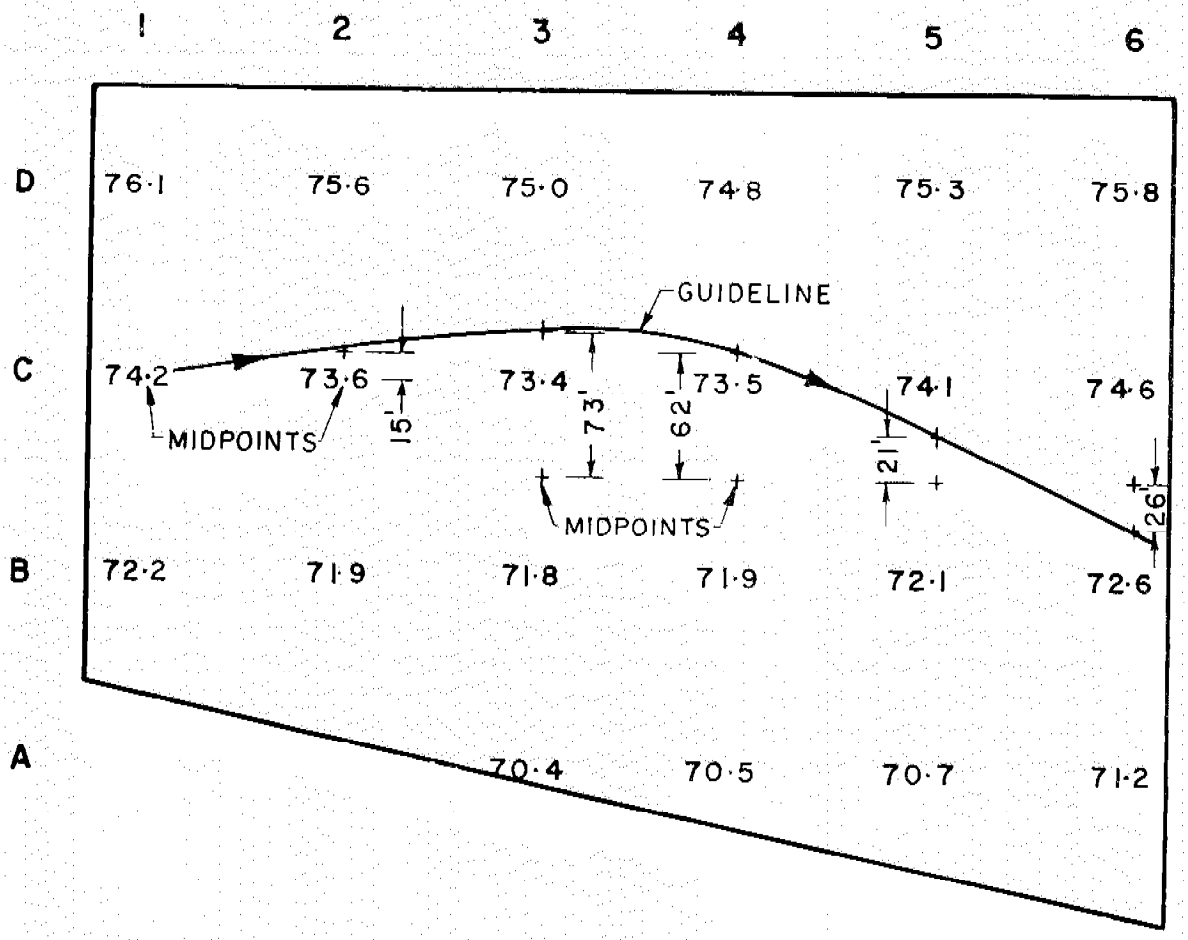
A point was then located 16 feet south of the average to the contour line and the stationing at that point checked against the original estimate. Since it was very nearly station 1+20, no further refinement was necessary. Similarly, points were found on random line b, c, d, etc. and the guidelines plotted.

Guidelines can also be located from a grid-type survey. This can best be described through the use of an example, figure 12-14. The elevations of each grid line approximately normal to the contour lines are first added and an average elevation for each line determined. Thus, on line 3, the sum of the elevations is

$$75.0 + 73.4 + 71.8 + 70.4 = 290.6$$

The average elevation is

$$\frac{290.6}{4} = 72.65$$



SUM OF ELEVATIONS	222.5	221.1	290.6	290.7	292.1	294.2
AVERAGE ELEVATION	74.17	73.70	72.65	72.68	73.03	73.55
PERCENT GRADE	1.95	1.85	1.53	1.43	1.50	1.53
STATION GUIDELINE	0+00	1+00	2+05	3+05	4+08	5+10
ELEVATION	74.17	73.97	73.76	73.56	73.35	73.15
ADJUSTMENT	0	+15	+73	+62	+21	−26

Figure 12-14.--Establishing guidelines for contour-bench leveling from grid map.

The average grade on each gridline is also determined. This usually can be done by subtracting the elevation on the lower edge of the field from the elevation on the upper edge and dividing by the distance (in stations) that the points are separated. For line 3, this becomes

$$\text{Percent grade} = \frac{75.0 - 70.4}{3} = 1.53 \text{ percent}$$

The average elevations are considered to lie on the midpoint of each grid line. Hence, on lines 1 and 2, the midpoint is on line C; but for lines 3, 4, 5, and 6, the midpoint is at B+50.

Calculations are then made to determine the adjustment from these midpoints. Starting at the midpoint on line 1 with an average elevation of 74.17 and assuming the grade of the guideline is 0.002, it is estimated that the point on line 2 will be approximately at station 1+00, and the desired elevation on line 2 is about 0.2 foot lower or 73.97. Since the average elevation of line 2 is 73.70, the desired point lies above the midpoint a vertical distance of

$$73.97 - 73.70 = 0.27 \text{ foot}$$

Since the slope is 1.85 percent, the adjustment to be made is

$$\frac{0.27 \times 100}{1.85} = +15$$

A point 15 feet above the midpoint was located, and the distance from the midpoint on line 1 was scaled. Since it is very nearly the estimated 100 feet, the point is satisfactorily located.

A similar calculation is made on line 3, then line 4, and progressively the horizontal position of the guideline is plotted.

Planning benches.--With the guidelines located, the engineer can then plan the bench location on the map as shown in figure 12-15. The closer the guidelines are followed, the less will be the earthwork required but compromises need to be made to eliminate point rows and conditions which will make farming difficult. In planning benches, the following points should be noted:

1. Avoid sharp bends. Normally tillage difficulties will be experienced if a deflection in alinement is over 45° sharper deflections can usually be broken into two segments.

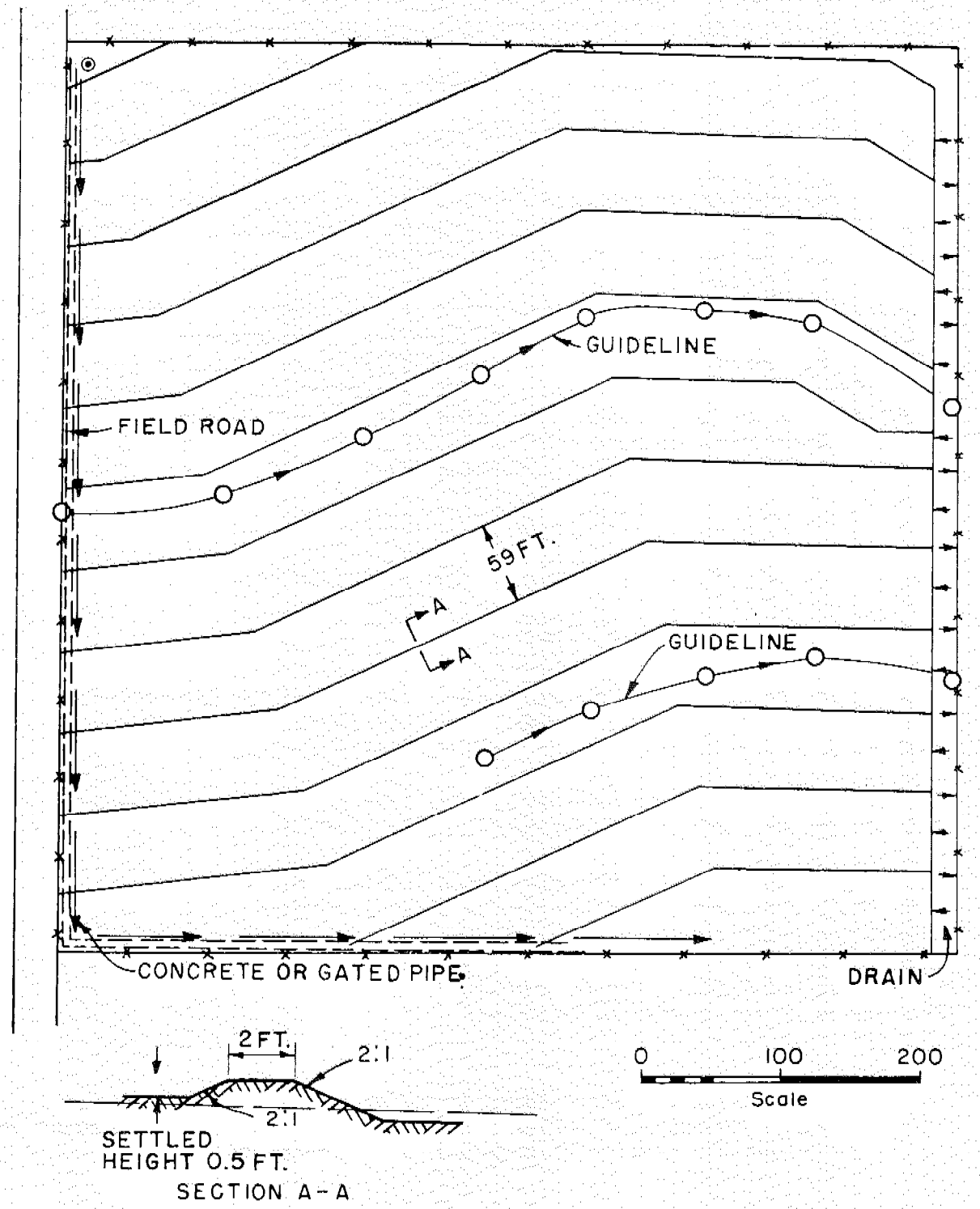


Figure 12-15.--Contour-bench leveling layout.

2. Normally benches should continue completely across the field. When it is necessary to terminate a bench in the middle of the area, remember to provide for an increase in the width of the dike and escarpment area for the adjacent benches beyond that point. An example of this is shown in figure 12-16 where this dimension was increased from 6 feet to 8 feet to take care of the increased vertical interval

3. Avoid pointed areas that are difficult to construct and maintain. Where one dike intersects another, make the angle of intersection about 90° in the manner shown on figure 12-14.

4. The bench spacing, T, should be changed whenever the average downfield slope at the location of the bench varies more than (1/2) percent from the slope used to calculate T. This insures the width of the bench, W, will be within 1+ foot from the intended dimension.

Staking.—The bench layout as planned on the contour or grid map must be transferred to the field. Usually one or two bench boundary lines are selected as controls and these are located on the ground by horizontal measurements from the points of reference for horizontal control established when the map was made. If a grid survey was used for planning, the bench boundaries may be established by measurement from existing grid stakes.

In figure 12-17 the lines F and J were selected. Line J was located in the field by first locating the ends of the east and west sides of the field. On the west, point (J) (0) was located 100 feet north of the fence corner. Point (J) (6+30) was located 20 feet west and 236 feet north of the southeast fence corner. One point of intersection was located by measuring 175 feet from point (J) (0) toward point (J) (6+30), turning a right angle and thence measuring 20 feet to the right. The other point of intersection was similarly located. All measurements were determined by scaling from the topog map.

Similarly, line F was located and the ends of lines 1, 2, 3, etc., were located along the north and south fence lines. The balance of the stakes were set by line and measurement as shown. The distance between the stakes on the numbered lines was calculated by the formula

$$\text{Distance} = \frac{\text{bench spacing, T}}{\text{sine of angle}}$$

For example, on the 2 line, figure 12-17, the bench width, T, was 59.0 feet and the angle was 64° 30 feet. Therefore, the distance along the 2 line was

$$\text{Distance} = \frac{59.0}{\text{Sine } 64^\circ\ 30'} = \frac{59.0}{0.903} = 65.3 \text{ feet}$$

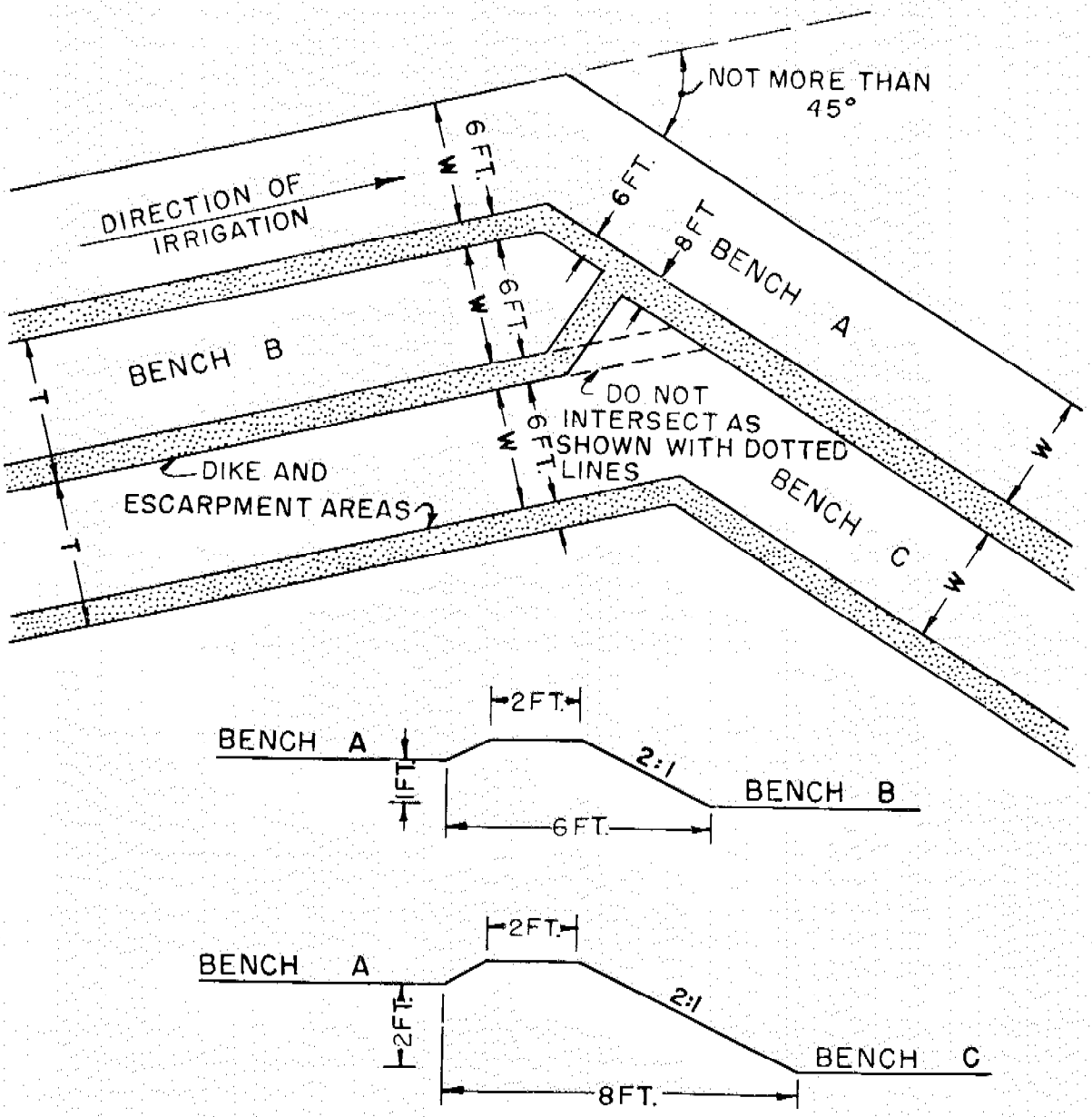


Figure 12-16.--Contour-bench details.

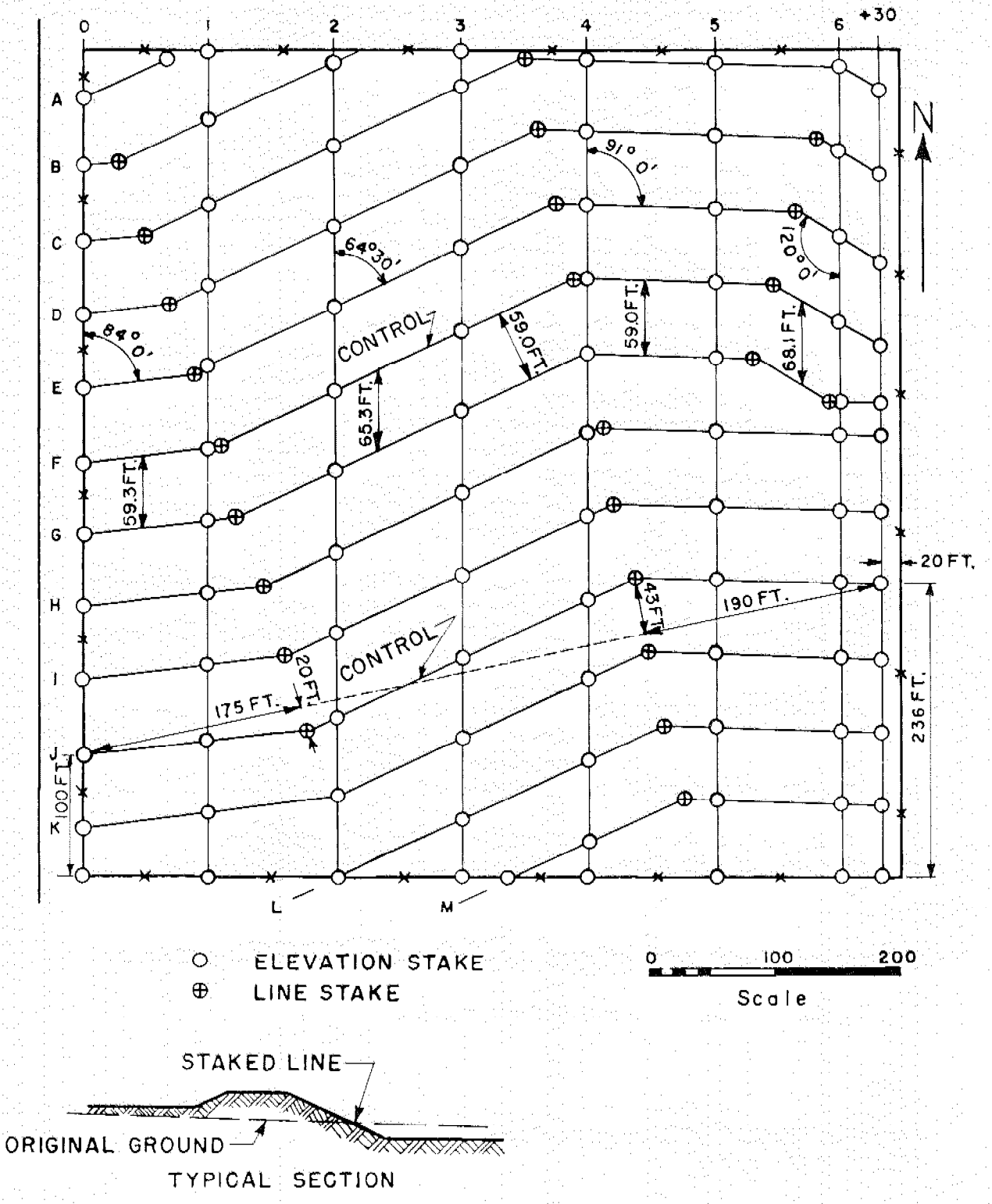


Figure 12-17.--Staking contour-benches--method 1.

After all stakes are set, elevation shots are taken for land-leveling design purposes. After the cuts and fills are computed, stakes are marked with a fill on one side for the area above and a cut on the other for the lower bench.

An alternate method of staking the field is shown in figure 12-18 The control lines are located as previously shown, and then the farmer uses row-marking equipment to carry parallel lines in both directions from the control lines to the adjacent bench boundaries. The farmer builds a small earth-marking ridge at each bench boundary using a border disk, single bottom plow, or similar equipment.

Stakes are then set on undisturbed ground on each side of the bench every hundred feet as measured along the centerline. For identification purposes, each bench is lettered, and the stakes are located by station and marked right or left, i.e., 3+00 L, or 3+00 R. No stake refers to more than one bench. While this method requires twice as many stakes as the one previously described, it is simpler, easier to stake, and each stake needs only one cut or fill marking. Difficulty may be experienced, however, in making accurate earth-volume calculations when this method is used.

Computing cuts and fills.--For purposes of leveling, each bench is regarded as a separate field. The plane method of land-leveling design is used with the single modification that the midpoint on the centerline is substituted for the centroid.

Figure 12-19 is an example of the calculations for one of the benches previously shown on figure 12-17. The average elevation of the bench was computed to be 90.46. The plane was then lowered 0.05 foot to provide the proper ratio between cut and fill.

The plane was further lowered sufficiently to provide earth for construction of the dike. This adjustment can be computed as follows:

$$\text{Cross-sectional area of dike} = \frac{\text{Top width x Base width x Height}}{2}$$

$$= \frac{2 \text{ feet} + 4 \text{ feet}}{2} \times 0.5 \text{ foot} = 1.5 \text{ square feet}$$

Assuming that it will require 50 percent more excavation to provide fill for the dike,

Cross-sectional area of excavation required - 1.5 x 1.5 square feet = 2.25 square feet

Bench spacing, T, = 59.0 feet

$$\text{Adjustment} = \frac{\text{Cross-sectional area required}}{\text{Bench spacing}} = \frac{2.25}{59.0} = 0.04 \text{ feet}$$

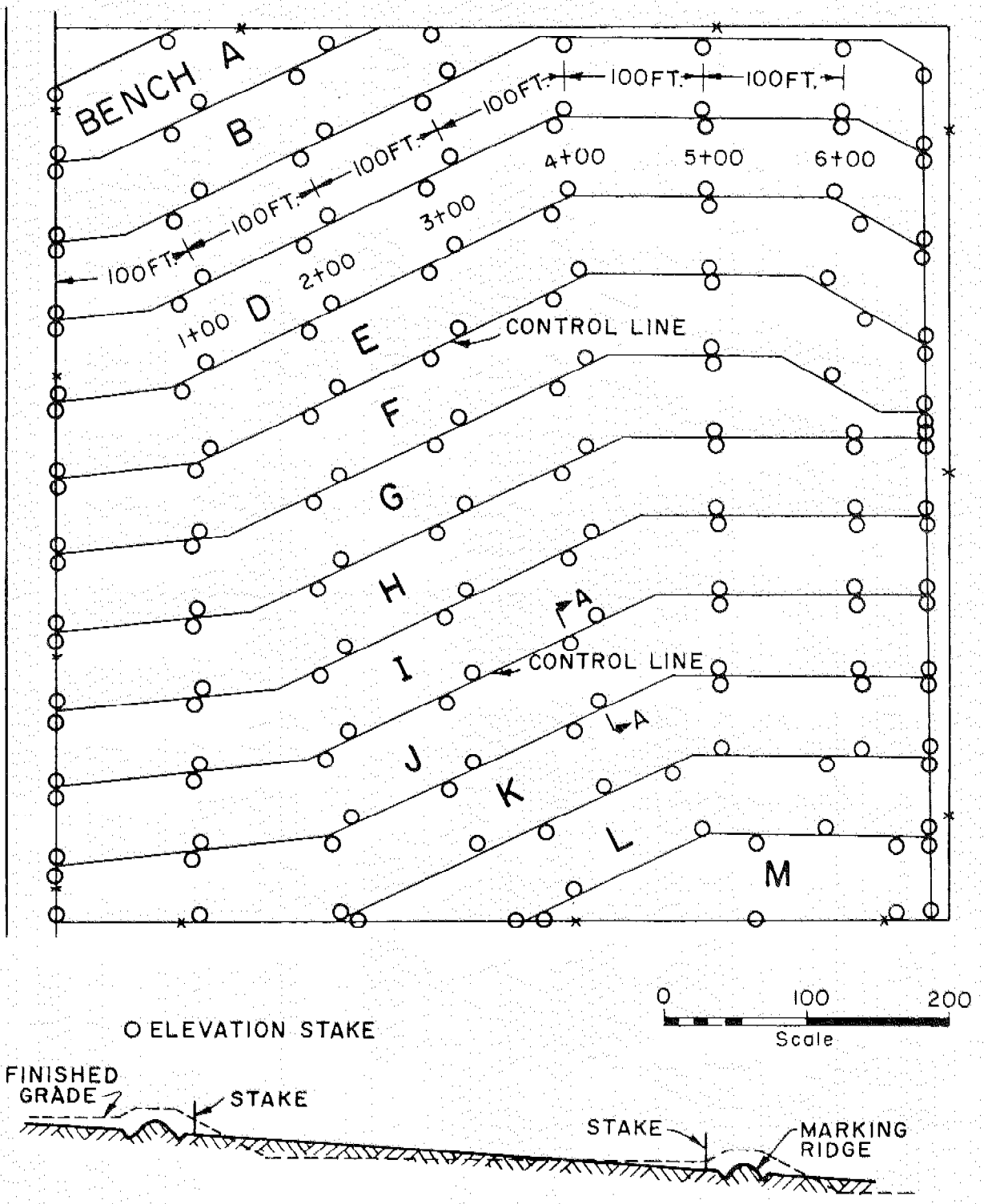
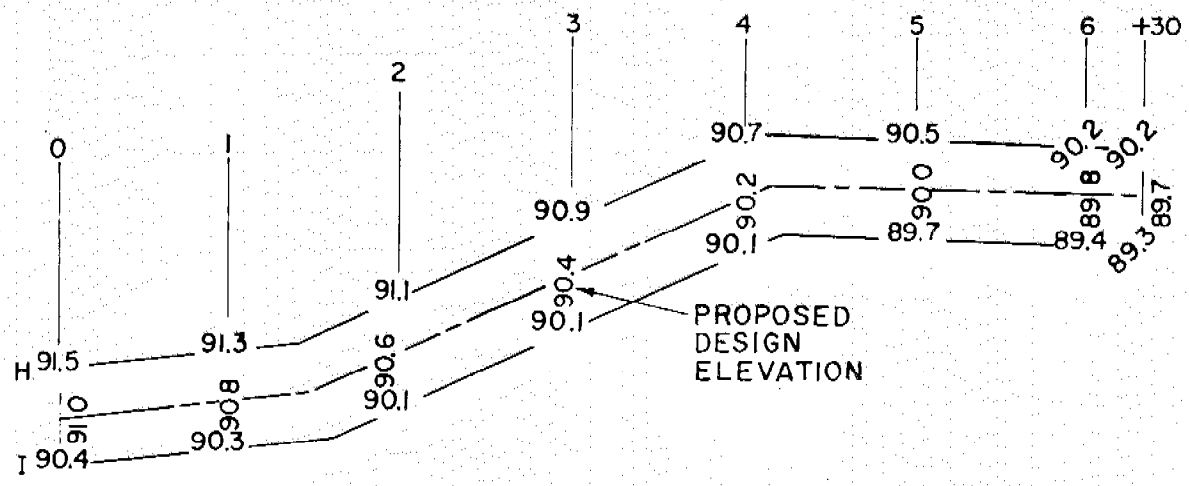


Figure 12-18.--Staking contour benches--method 2.



AVERAGE ELEVATION ON H LINE = $\frac{91.5+91.3+91.1+90.9+90.7+90.5+90.2}{7}$

LINE 0 TO 6 = = 90.89

AVERAGE ELEVATION ON I LINE = $\frac{90.4+90.3+90.1+90.1+90.1+89.7+89.4}{7}$

LINE 0 TO 6 = = 90.02

AVERAGE ELEVATION AT MIDPOINT = $\frac{1}{2}$(90.89 + 90.02) = 90.46

LESS ADJUSTMENT FOR SHRINKAGE	-0.05
LESS ADJUSTMENT FOR RIDGE	-0.04
DESIGN ELEVATION (LINE 3)	90.37 (90.4)

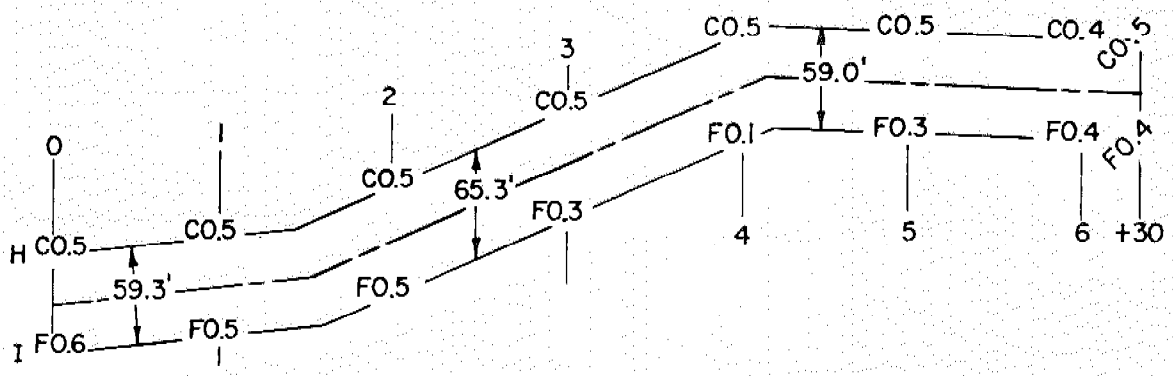


Figure 12-19.--Leveling calculations for contour benches.

The design elevation at the midpoint was computed and by applying the desired grade (0.002) from that point, the design elevations at all other points were calculated.

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