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PRELIMINARY ESTIMATES FOR IRRIGATION PROJECTS

THESIS FOR DEGREE OF C. E.

HOWARD H. BARNETT.

1914

THESIS

P R E L I M I N A R Y E S T I M A T E S

for

I R R I G A T I O N P R O J E C T S.

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I N T R O D U C T I O N.

Though much has been written on the subject of Preliminary Estimates for Irrigation Projects there is yet much ground for discussion and an exchange of ideas, as the field is a broad one and each new project presents new problems. The work lies in the realm of the art rather than in the science of engineering and the experience, skill and good judgment of the engineer in charge determine largely the accuracy of the results.

Usually certain restrictions as to time and expense are placed in advance and since the means to the end must conform to these, no hard and fast rules or methods of proceedure can well be laid down. Methods that one engineer finds rapid and accurate may not be applied to advantage by another. Under no circumstances, however, should an engineer permit himself to be so restricted as to be tempted to slight the work and produce inaccurate results. Such a proceedure may entirely defeat the object of the survey and end in trouble and disappointment.

This leads to the question of what may be considered a reasonable degree of accuracy. Experience seems to warrant the assertion that under average conditions, with reference to design and construction, the estimate should be within at least ten percent of the actual cost. On small systems where the structures are plain and conform closely to common practice an estimate may be expected to be within five percent of the actual cost. On the other hand where the design is novel, more or less elaborate in details, conditions new and undetermined, greater fluctuation must be anticipated and the leeway should be increased to fifteen or twenty percent.

In the following discussion it is the purpose of the writer to outline certain field and office methods which have been found both rapid and reasonably accurate in results. It is not intended to treat the subject in its broadest sense and so all matters pertaining to source and amount of water supply, rain-fall and run-off, water rights, right of way, etc. are purposely left out and the question for discussion may be stated briefly as follows:-

Assuming that there is water on the one hand and land on the other, what will it cost to put the water on the land?

-:GENERAL CONSIDERATIONS:-

A. TYPICAL IRRIGATION SYSTEM:

At the outset for the sake of clearness, we may outline briefly the essential elements of a typical irrigation system as follows:-

1. Diversion Works.
2. Inlet Canal.
3. Reservoir.
4. Outlet Canal (or Canals.)
5. Laterals.

1. DIVERSION WORK:

The diversion works consists usually of a combination dam and headgates, its function being to intercept the waters of the stream furnishing the supply and divert a specified amount at certain seasons for use in the system, the amount and the time of the diversion or appropriation from any particular stream being limited by prior water rights, (or the amount of free water available,) and also by the amount asked for or actually needed. If the steady flow of the stream has already been appropriated by prior rights then the only waters available are the flood waters at comparatively short seasons of the year. Consequently the dam and headgates must be designed to meet the requirements - be of large capacity and able to resist flood conditions. On the other hand, if it is desired to appropriate only the steady flow then the works may be of smaller dimensions and so designed as to offer little resistance under flood conditions.

2. INLET CANAL:

If the headgate is of large capacity the inlet canal must be correspondingly large and when a large quantity of water is to be conveyed a long distance, open canals having a suitable grade are usually employed. Such canals have some objectionable features, one of which is a considerable loss by evaporation and seepage, the latter being an unknown quantity until the canal is built and put in operation. They must also follow a nearly uniform and easy grade. The condition that makes it necessary either to skirt along the valleys which they encounter, thereby greatly increasing their length, or to cross these valleys on aqueducts, which are always more or less expensive structures.

When the volume of water to be conveyed is not too great, canals can be replaced by flumes or pipe lines. Pipe lines may be either cast iron, wrought iron, steel, or wooden stave pipe, differing from canals and flumes in the fact that they are not confined to a uniform grade but may go up hills and down and, if necessary, may be laid in the bed of any streams which they may cross.

At a point near the headgate and at frequent intervals throughout the length of the canal, there are waste-gates constructed in the banks of the canal for the purpose of preventing the water rising too high and also for letting the water entirely out in the case of a break in the canal bank.

Near the headgate is usually a gauging flume or weir for the purpose of measuring the amount of water flowing. If the water entering the canal is heavily charged with silt and sediment, it is necessary to provide some means for clarification. What is known as a sand chute is usually provided for this purpose and located just below the headgate. It is a combined flume and waste-way, so designed that the velocity of the water is checked and a certain amount allowed to waste from the bottom of the flume. This carries away the heaviest of the sediment.

3. RESERVOIR:

Storage reservoirs are almost invariably formed by building a dam across some valley and thus forming an artificial lake. Good reservoir sites are not by any means plentiful and common practice is to first find the reservoir and then locate the inlet and outlet canals from it.

The required capacity of the reservoir is determined chiefly by the amount of land to be irrigated but is influenced slightly by evaporation and seepage. The method of determining the capacity of the reservoir will be considered under the head of "Duty of Water."

The principal structures connected with the reservoir, are the dam, outlet gates and spillway. These structures are of various types and designs which it would be impossible to consider in detail. In some cases all three are combined in one, while in others each may be separate, as for instance, the outlet may consist of a tunnel through the base of one of the hills adjacent to the dam, while the spillway may be located in a depression in one of the surrounding ridges.

4. OUTLET CANAL (or CANALS.)

The outlet canal extends from the reservoir to the land to be irrigated and may be called the main artery of the distribution system. Where the reservoir is formed by the means of a dam across a valley it is often feasible and desirable to have two outlet canals, one on each side of the valley. However this is a matter entirely dependent upon the topography of the region and the location of the land to be irrigated.

The facts regarding evaporation and seepage, grade, flumes, pipe lines, etc. as given under the "Inlet Canal" apply equally well to the outlet, and the same influence that determines the capacity of the reservoir also controls the capacity of the outlet ditch and will be considered in the discussion of the "Duty of Water."

5. LATERALS:

As may be inferred from the foregoing, the laterals furnish the means of conveying the water from the main outlet to the individual tracts of land and the required capacity of each lateral is determined by the amount of land it serves.

VARIATIONS:

While our typical system as outlined above contains five main features, it very often happens in practice that some of these can be eliminated or combined. Sometimes a very desirable reservoir site may be found in the channel of a stream furnishing the water supply, in which case a high dam may serve both the purpose of impounding and diverting the waters and the inlet canal be entirely dispensed with. Again the dam may serve only for storage of water letting it flow down the river channel and diverting it as needed at a point as near as may be to the territory to be irrigated. In this way a considerable length of conduit may be saved. Many of the early systems built when water was plentiful consist only of a low diversion dam and canal, appropriating water directly from the stream whenever needed, having no occasion for storage.

B. DETERMINING FEATURES:

1. DUTY OF WATER:

A great deal could be written on this subject alone. It is the purpose here, however, to consider it only briefly in connection with the determination of the capacity of the reservoir and outlet ditches.

The duty of water in irrigation may be defined, in general terms, as the ratio of the area of the land to the quantity of water required to irrigate it during a full season. It may be properly, though not commonly, expressed in acres covered by a cubic foot of water per second per irrigation season. Expressed in this way, the duty varies from 10 to 100 acres throughout the West. A good average value is 70 acres. However a high duty for one locality may be low for another. In California the duty ranges from 10 to 50 acres while in Colorado it ranges from 50 to 100.

A more common expression for the duty of water is the total depth of irrigation water required to produce a crop economically. It is usually given in feet and varies from one to ten. For instance, in a given locality it may be known that a good crop of alfalfa can be irrigated by the proper application of a total of 2.5 feet of water during an irrigation season. The use of 3 feet of water would be a waste and the duty would be lowered in proportion.

In figuring the capacity of the outlet canals and laterals, the duty of water as expressed first above is made use of. Suppose it is found by study of local conditions that a duty of 80 acres is proper. Then the capacity of the main outlet canal must be 1 sec.-ft. for

every 80 acres of land to be irrigated, that is, the total acreage divided by 80 gives the required capacity of the outlet canal:-

$$\frac{\text{Total acreage under canal}}{80} = \text{required capacity of canal}$$

$$\frac{\text{Total acreage under Lateral}}{80} = \text{required capacity of lateral}$$

In determining the required capacity of the reservoir, the duty as expressed in depth of water required during a season is made use of. The common unit of quantity is the acre-ft. or 43,560 cu. ft. A depth of 2.5 ft. of water over one acre is equivalent to 2.5 acre-ft. If the duty for any particular locality is found to be 2.5 ft. then the capacity of the reservoir must be 2.5 acre-feet for every acre of land watered.

The connection between the two ways of expressing the duty of water may be shown as follows:- Assuming a duty of 80 acres per sec.-ft. to find the equivalent depth. Assume further that the outlet canals are to run full 100 days during the irrigating season, which value is close to the average for the Western States. Then each 80 acres being entitled to 1 sec.-ft. continuous flow, receives during 100 days a total of

$$100 \times 24 \times 60 \times 60 = 8,640,000 \text{ cu. ft. of water.}$$

Therefore 80 acres equals 3,484,800 sq. ft. receives a total depth of $8,640,000 \div 3,484,8000 = 2.5$ ft.

The U. S. Department of Agriculture has for many years been making experiments and collecting statistics relative to water duty, the results of these investigations being published from time to time in the form of bulletins. Reference to them is often of material aid in determining the duty of water for any particular locality.

In canals and reservoirs the effects of evaporation and seepage must be taken into account. These elements vary with the length of the canal, kind of soil, area of exposed water surface, design of canals and conduits, methods of construction,and so cannot be estimated closely in advance. The U. S. Department of Agriculture is making a thorough investigation of the losses due to these causes and much valuable information may be gained by a study of the government publications on this subject. It may be said, however, that the combined loss due to evaporation and seepage will not ordinarily exceed ten percent though it has been known to approximate 90 percent in at least one case - The Gage Canal of California.

2. IMPORTANCE OF RESERVOIR:

As mentioned above, the reservoir is in many cases the determining element in the system. The first question raised in connection with any proposed system almost invariably pertains to the location and size of the reservoir. A good reservoir site in an arid region

is considered a find. It ranks with a gold mine in commercial importance. Broad acres of good fertile land can be found adjacent to almost every stream. Torrential floods of water flow down these streams at certain seasons of the year. The missing element is the means of storing this water and permitting its use when crops are thirsty and the sky is cloudless.

3. COMMENCEMENT OF SURVEY:

a. INLET CANALS:

With the reservoir question settled, the next query pertains to the inlet canal. Taking the high water line of the reservoir as the low point, the problem is to find the most economical route to the river or source of supply. The work of location usually proceeds from the reservoir to the river channel. The shortest route may not be the most economical and the problem may resolve itself into a choice of several routes. Rock cuts, flumes, tunnels, pipe lines, etc. are likely to be required more on the inlet than on the outlet and a careful study of all conditions is necessary as these elements affect the cost greatly.

b. OUTLET CANAL:

In the location of the outlet canal the diversity of routes may be even greater than with the inlet, but the problem is much the same; that is, to find the most economical and desirable route between the low point of the reservoir and the high point of the land.

Where there is plenty of fall to be utilized, or in other words, the good land, is considerably below the reservoir, then it may be expedient to keep the velocity of the flow in the various sections of the canal right up to the limit that the material will stand and thus reduce all parts to the smallest possible dimensions. Usually, however, the reverse is true. There is no grade to spare. In order to reclaim as much of the good land as possible, the canal must be put on its highest line by reducing the grade to a minimum. This means increasing the cross sectional dimensions of all the parts and consequently the cost. It then devolves upon the engineer to determine whether the value of the land gained will be sufficient to offset the added cost of construction.

4, USE OF GOVERNMENT TOPOG'L MAPS.

The outlet of the reservoir being the highest point in the outlet canal, the operation of location will usually proceed from here. As an aid in determining the controlling features in any proposed system, the government topographical maps will be found of great value. The

contour lines will show quite accurately the relief of the land, the fall of the stream, approximate elevation, etc., and a careful study of the maps will be time well spent.

C. CONSTRUCTIONAL PROBLEMS:

Having determined the required capacity of the main canals, the next operation is to calculate and fix upon the various dimensions and arbitrary details that enter into the practical working out of the system.

a. KUTTER'S FORMULA:

As mentioned before the capacity of the inlet canal will be governed by the amount of water appropriated or by the cost, being as large as conditions demand or will permit.

The capacity of the outlet canal will be determined by the amount of land to be watered.

Knowing the required capacity of each of these canals, their respective dimensions may readily be calculated by Kutter's Formula in conjunction with the other well known hydraulic formulas.

Any reliable hydraulic text-book treats these formulas in detail. It is considered unnecessary to discuss them here. However, Plate I shows their application in the solution of a practical problem.

b. VELOCITY:

A matter of first importance is that of velocity of flow. The permissable velocity varies, of course, with the kind of material. In a light sandy soil a surface velocity of 2.3 to 2.4 ft. per sec. or a mean velocity of 1.85 to 1.93 ft. gives best results. Velocities of from 2 to 3 ft. are ordinarily sufficient to prevent the growth of weeds and the deposition of matter in suspension. And other things being equal, this velocity should be maintained wherever possible. Ordinary firm sandy loam, or soil permits velocities of 3.0 to 3.5 ft. per sec., while in firm gravel, rock or hard pan the velocity may be as high as 5 or 7 ft. Brick work or heavy dry-laid paving or rubble will not stand velocities higher than 15 ft. per sec. and only the most substantial form of masonry construction is capable of resisting still higher velocities.

c. SIDE SLOPES:

The question of side slopes also depends on the kind of material. It may vary from 2 horizontal to 1 vertical in light sandy soil to ¼ to 1 or even vertical in masonry canals and rock cuts. The following table gives the slopes commonly used for various materials:-

Soil.	Cut Slope	Fill Slope
Sand or sandy gravel,	2 to 1	2 to 1
Loam,	1½ to 1	1½ to 1
Clay and clay gravels,	1 to 1	1½ to 1
Hard pan,	½ to 1	1 to 1
Solid rock,	¼ to 1 or vertical	as it stands

d. BANKS:

In the case of side hill or sloping ground, only one bank is ordinarily required but where the surface is quite level banks on both sides of the canal are necessary. The top of the bank is usually from 1 to 3 ft. above the high water line of the ditch and the width at the high water line should never be less than the depth from the top of the bank to the bottom of the ditch.

e. FORM OF CROSS SECTION:

A study of the hydraulic formulas used in determining the capacities of the canals and conduits shows that the form of the cross section having a minimum perimeter for a given area produces the greatest velocity of flow and therefore gives the greatest capacity. The semicircular form for an open channel meets this condition but since it is seldom convenient to construct a channel of this form, a semi-hexagonal section is the nearest practical approach to it. Sometimes other considerations

make the semi-hexagonal section undesirable. In case this form of cross section produces too high a velocity of flow it may be reduced to the proper limits by making the channel wider and shallower. And further, in shallow soils this wider and shallower channel may be especially desirable in order to avoid shale or rock excavations. A deep canal is more difficult both in construction and in maintainance than a shallow one.

f. CURVES:

The maximum degree of curvature for any particular canal depends upon the size of the channel and upon the velocity of flow or what is the same thing the kind of material. Shorter curves may be used in a draw than on a point and an easy curve at the end of a long tangent is desirable on account of the wave action, especially if the curves occursin a fill.

Newell in his work on Irrigation Engineering, gives the following in regard to curvature:- "The precise amount of resistance that a curve offers to a flow of water in open channels has not been definitely determined. It is believed, however, for velocities of flow which are safe for earthen canals, that a curve in the center-line whose radius is 2.5 times the bottom width of the canal may be used without any appreciable effect on the average rate of flow."

g. ECONOMIC CUT:

In laying out irrigation ditches with single or double banks, it is necessary to determine in advance the cut required at the center of the ditch so that the excavation will just make the embankment, plus shrinkage and waste. This is called the economic cut. It varies, of course, with the slope of the ground at right angles to the center line of the canal.

The economic cut for level ground may readily be determined by equating similar expressions for the cut and fill areas. It should be determined for both single and double banks and for sloping as well as level ground. Plates V and VI will aid materially in determining the effect on the center cut of changes in surface slope.

FIELD OPERATIONS.

A. ORGANIZATION OF PARTY:

The method of proceedure that the writer has found both rapid and economical in the location of a canal line requires nine field men besides two teamsters with double teams and covered wagons. The nine men are divided into three parties as follows:-

1.	Fly line	1. Levelman
		2. Rodman
		3. Stakeman
2.	Stake Line	1. Head Chainman
		2. Rear Chainman
		3. Stake man
		4. Engineer in charge
3.	Level Line	1. Levelman
		2. Rodman

1. PERSONEL:

In choosing the men for the various positions I have found that it pays handsomely to have a good fast roadman. He is, in fact, the life of the outfit. The roadman for the fly line party sets the pace for all the rest. If he is slow in moving from station to station, the work is sure to drag and the whole outfit will lack the snap and vim that is quite essential to rapid and harmonious work.

The chain men should be impressed with the necessity of being careful and conscientious in their work — leaving nothing in doubt. They should never be tempted through fear of sharp criticism or reprimand to cover up some mistake or let an error pass uncorrected.

In engaging the men for the various positions, it should be distinctly understood at the outset that they may be shifted or changed around as the engineer in charge may see fit at any time. The first few days in the field will reveal who are the leaders and whether any changes should be made in the assignments of work.

2. SIGNALS:

The sign language used in field operations is common knowledge with all who have worked in the field, yet it varies to some extent with the individual. The following are a few signals which the writer has found effective:-

<u>a</u>. Either arm extended straight down and waved back and forth in front of the body means variously: 1. No good. 2. Not right. 3. Cant understand. 4. Do it over again.

<u>b</u>. Either arm extended straight over head and moved slowly either to right or to left means to hold rod or flag pole plumb.

<u>c</u>. Either arm extended above and swung in a circle over the head means to make a turning point.

<u>d</u>. The numerals from 0 to 9 may be signaled as follows: Standing erect with hands on chest and elbows against sides of body:-

0. = Both arms extended over head in the form of a circle with hands touching.

1. = Right arm with hand open extended straight up.

2. = Right arm extended straight out horizontally.

3. = Right arm extended down at about 70 deg. from the horizontal.

4. = Left arm extended straight up.

5. = Left arm extended straight out horizontally.

6. = Left arm extended down at about 70 deg. from the horizontal.

7. = Both arms extended straight up.

8. = Both arms extended straight out horizontally.

9. = Both arm down at about 70 deg. from horizontal.

B. SURVEY OF CANALS:

1. FLY LINE:

The object of the fly-line party is to make an approximate temporary location of the surface grade line based on the economic cut. For instance, assume that the elevation of the ditch bottom at Station 0 is 100.00, also that the economic cut for level ground is 1.73 and that the grade is 0.1 ft. per 100 ft. Then the surface elevation for Sta. 0 will be 101.73 ft.; for Sta. 1, 101.73 - 0.1 = 101.63 (going down grade); for Sta. 2, 101.53, and so on. The stakes used in this line are lath so that they can be clearly seen for a considerable distance. A lath is set at Sta. 0. The rodman then gives the levelman a reading at this station. Suppose the reading in this case to be 6.82. This gives a height of instrument of 101.73 + 6.82 = 108.55. (The form of notes used in this work is that commonly used on any uniform grade line). The rodman now sets his target at 6.82 + 0.1 = 6.92 and proceeding in the direction of the grade contour, paces off a distance of 100'. The levelman here directs him up or down until, with the bottom of the rod on the ground, the cross-hair cuts the center of the target. A lath is here driven marking approximately the position of Sta. 1. The rodman now sets his target at 6.92 + 0.1 = 7.02 and proceeds another 100' by pacing to Sta. 2, and so on pacing from station to station setting a lath at each one. Continuing

in this manner for 1500 or 2000' the surface grade line is approximately located. The error due to pacing this distance may be as much as 200' but as this would only affect the grade elevation by 0.2', it would not have much effect on the altitudinal position of the lath. However, continuing much farther would make the error in grade quite appreciable, and so at about this point a correction should be made. In order to make this correction it is necessary that the stake line be brought up nearly to the point in question.

2. STAKE LINE:

The object of this party is to locate the center line of the canal proper; This should be a practical location that will not admit of much subsequent variation. The judgment and skill of the engineer is here called into play and he must be able to decide important matters quickly and accurately. He must be able to determine without too much delay whether to follow around a point or make a cut; follow up a draw or put in a flume, and a careful study of the relative costs of the various kinds of construction is necessary in advance, in order to make the proper selection. The stakes used in the location of this line should be about 1" x 1½" x 18" long, saw-pointed.

The work of location proceeds as follows:- The head chainman leads the party, with him goes the stake man.

The engineer with a flag pole in hand takes his position one hundred feet behind the rear chainman. A stake "Sta. 0" marked lengthwise and faced to the rear is set at the first lath as located by the fly-line party. The head chainman then proceeds in the direction of the second lath here setting a stake marked "Sta. 1" at exactly 100' from "Sta. 0". At "Sta. 2" the head chainman sights back for alignment to the engineer who is now at "Sta. 0". The engineer guided by the line of lath along the grade line, directs the location of each successive stake. A long tangent may be put in where a number of lath come approximately in line. If the ground is sloping he directs the stake line a few feet above the lath line, or in other words, he throws it "into the cut". In rounding a point he also goes deeper into the cut. He cuts across the upper end of a draw by means of a fill or flume instead of following to the extreme point of the draw.

In running in curves the engineer simply steps out, at right angles, from his station the proper deflection distance for the desired curve and there sets his flag pole. The head chainman puts himself in line with the flag pole and rear chainman. If the curve is quite sharp 50' or even 25' stations are put in so as not to have the chord differ much in length from the arc.

When the stake line has nearly reached the end of the lath line, the rodman of the fly-line party takes note of the station number, corrects his grade elevation accordingly and beginning at the last station in the stake line, locates a new lath line as before. The stake man of the fly-line party meanwhile goes back to the rear of the stake line party and pulls up the lath previously set for use again in extending the fly-line.

3. LEVEL LINE:

The object of the level party is to take the elevation and surface slope at each station. If the ground is level, or nearly so, one reading only is necessary, but if the ground is sloping two reading are required, one at the stake and one at the center line of the embankment. Notes should also be taken recording the surface material, whether single or double banks are required, the nature and profile of all gullies, creeks, or precipitous places etc.

It may be necessary to investigate the nature of the sub-soil, especially if there is any possibility of the surface being underlaid with a stratum of hardpan or rock. The means of determining this condition will be discussed later under the head of Classification of Material.

The form of notes which the writer has found effective in this work is shown on Plate IV.

Referring to this Plate, the columns 1, 2, 4, 5, 7, 8, and portions of 3 and 6 are obtained in the field. The remaining columns represent the work involved in the reduction of the notes which is discussed further on and shown in detail on Plate VII.

4. TRANSIT PARTY:

Unless it is desired to make a State or Government filing, or questions of right of way enter into the estimate of cost, it is not necessary to immediately run a transit line over the location. However this work should follow shortly as the stakes soon become dislodged and portions of the line may be obliterated. Alternate freezing and thawing will cause stakes to rise in the ground and fall over. Ordinarily the transit location is not necessary for the estimate of cost and an explanation of the field work will not be entered into further than to say that it involves nothing uncommon to usual practice in traversing.

C. SURVEY OF RESERVOIR BASIN:

A reasonably accurate survey of the reservoir basin is essential in order to determine the height of the dam required to give the desired amount of storage. Three methods are commonly employed in this work, viz:

1. Contour Method.
2. Cross Section Method.
3. Stadia Method.

1. CONTOUR METHOD:

The contour method is perhaps more generally used than any other probably on account of its simplicity and directness. The contours are usually run 5' apart in elevation, although sometimes they are located every foot. For preliminary purposes 3 to 5 foot contours are quite sufficient and intermediate contours may be found by interpolation.

In carrying out the work by the contour method, two parties are required, a level and a transit party, although one party may be made to serve both purposes, first locating the contour lines and then traversing them. The method of locating the contour lines is clearly explained in almost every text book on surveying and will not be discussed here.

2. CROSS SECTION METHOD:

The cross section method is best suited to reservoir basins of considerable regularity in shape and contour, and not too thickly wooded. It consists essentially in running a number of parallel profiles in two directions, usually at right angles to each other, across the reservoir basin. These parallel lines may be 100, 200 or 500' apart and by platting to a suitable scale on cross section paper contours may be sketched in by connecting points of equal elevation, then the areas of the contours determined by counting the number of squares enclosed or by some other means.

3. STADIA METHOD:

For accuracy and rapidity the transit and stadia method undoubtedly surpasses the others. The chain and level being here dispensed with, a smaller party may be utilized and much rougher country traversed with little difficulty. This subject is thoroughly treated in any reliable work on surveying and will not be further dealt with here.

D. SURVEY OF RESERVOIR DAM SITE:

1. LOCATING CENTER LINE:

Having determined upon what seems to be a feasible dam site, the first operation is to locate the center line. This line should be staked from end to end at every change in the slope of the ground and at every 100' station. Distances should be measured along the slope of the ground from stake to stake. These distances used in connection with the relative elevation of the stakes will enable the horizontal length of the dam to be calculated more accurately than could be determined by measuring horizontally with a chain and plumb bob.

2. CROSS PROFILES:

A each stake a cross profile should be taken at right angles to the center line of the dam. These cross profiles should extend several hundred feet each way from the center line so that all topographical features at or near the dam site will be shown.

3. TEST HOLES:

Test holes should be dug to bed rock or solid material every 50 or 100' along both the center line and the inside toe of the dam as near as may be. A profile should then be taken over the line of the test holes showing the depth of the bed rock and other various changes of material.

Plates II and III show the center line profile and cross profiles of an actual dam.

E. SURVEY OF DIVERSION DAM SITE:

All that is given above in regard to survey of reservoir dam site applies equally well to the diversion dam site. In addition, however, a more careful determination of the nature of the foundation and depth to bed rock will probably be necessary in order that the dam may be properly designed to intercept the underflow.

F. CLASSIFICATION OF MATERIALS:

a. USUALLY THREE CLASSES.

It is almost always necessary to differentiate in some manner between the several kinds of material encountered in the excavation of the canals and laterals. There are various, and sometimes quite elaborate, means for grading the material, but in general only three classes are recognized, viz:

1. Earth
2. Loose Rock.
3. Solid Rock.

The means generally employed to distinguish between the three classes is based upon the relative difficulty of plowing. The classification is frequently defined about as follows:-

Earth shall include all materials that can be plowed with a good plow and a team of not more than four good horses.

Loose rock shall include all material, not earth, that can be plowed with a good plow and a team of not more than six good horses.

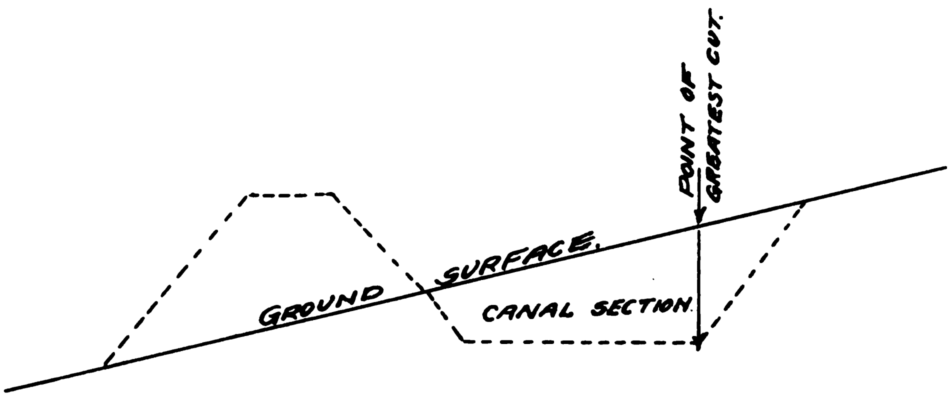
Solid rock shall include all material not classed as earth or loose rock.

The prices paid for the three kinds of material average about:-

15¢ per cu. yd. for earth.
40¢ " " " " loose rock.
$1.00 " " " " solid rock.

b. TESTING FOR MATERIAL:

In preliminary work it is impossible to apply the above plow test and other means must be resorted to in order to make a reliable estimate. The usual method is to sink test holes at every alternate station throughout the length of the canal. This may be done with an earth augur. The holes should be driven a little below ditch bottom at the point of deepest cut. See Sketch.



Another quick and reliable method of testing, is to drive down at the point of the greatest cut, a dull pointed steel bar. The ease with which the bar drives and also the sound of the blows will reveal the nature of the material. The bar may be pulled from almost any depth by means of a chain and lever. This method has been used by the writer on many miles of ditch work and has given excellent results.

OFFICE WORK.

1. REDUCTION OF NOTES:

a. USE OF INSTRUMENTS:

The work of reducing the notes and computing the quantities of the various materials may be relieved of much of its tediousness by the use of end area tables, cross section paper, the planimeter and the adding machine. The initial cost of the instruments mentioned may seem excessive but the time saved on two or three projects will prove a good return on the investment.

b. CAPACITY OF RESERVOIR:

The capacity of the reservoir and the size of the dam will probably be the first matters to determine. By whatever method the reservoir may have been surveyed, if it is platted on cross section paper to the proper scale, the work of computing the areas of the contours will be greatly facilitated. The main portion of the central area for any contour can be obtained directly by counting the squares, and the remaining odd shaped portions around the edge may be measured by the planimeter, or cut up into triangles and trapezoids and the areas computed. Both methods should be used as a check. Having computed the area of each 3 or 5' contour, as the case may be, the next operation is to interpolate for the intermediate one foot areas. The following is a simple reliable formula for this purpose:

LET A = LARGER AREA.

B = SMALLER AREA.

n = NUMBER OF AREAS BETWEEN A AND B.

THEN: $\frac{\sqrt{A}-\sqrt{B}}{n+1} = a$ = AMOUNT OF CHANGE PER $\sqrt{AREA}$.

THEN: $(\sqrt{B}+a)^2$ = 1ST. AREA GREATER THAN B.

$(\sqrt{B}+2a)^2$ = 2ND. " " " ".

$(\sqrt{B}+3a)^2$ = 3RD " " " ".

$(\sqrt{B}+na)^2$ = nTH. " " " ".

$(\sqrt{B}+(n+1)a)^2 = A$.

Adding together any two adjacent areas and dividing by two gives approximately the volume between the areas. This is near enough for estimating purposes although the use of the prismoidal formula in computing the volumes would give results more nearly correct.

Beginning at the bottom of the reservoir, the volume between contours should be summed up to a point SUCH that the total volume equals the required capacity of the reservoir. The height thus found fixes the high water line of the reservoir and from this the height of the dam may be determined, allowing 7 to 15' between the high water line and the crest of the dam.

c. VOLUME OF DAM:

The determination of the kind, shape and size of the dam is a matter too involved to be dealt with here, but no matter what the material or shape, it is invariably essential to determine the cubic contents. By means of a cross profile drawing such as shown on Plate III made to the proper scale, the cross sectional area above each cross profile may readily be determined. Adjacent areas averaged and the mean thus found multiplied by the horizontal distance between gives the volume between the areas. Summing the volumes thus determined gives the total volume of the dam.

d. VOLUME OF CANALS:

The quantities in the canals is next in order for determination. In the reduction of the field notes it is an excellent plan to have two men working together checking each other in computations as they go along. And further if loose leaf note books are used, several groups may work simultaneously and thus save much time.

1. TABLES AND DIAGRAMS:

Plates IV, V and VI.

There are five operations necessary in the reduction of the notes as shown on Plate IV. The first operation gives the surface elevations at the center line of the cut and at the fill (Columns 3 and 6); The second operation gives the amount of the cuts and fills (Columns 8 and 9); The third, gives the cut and fill areas (Columns 10 and 11); The fourth gives the average or mean areas (Column 12); and the last is simply the operation of totalling and reducing to cubic yards. The first two operations are self-explanatory but the last three may not be so readily understood. The operation of determining the cut and fill areas

involves the use of end area tables shown on Plate V and the diagram on Plate VI.

The following formula was utilized in computing the tables on Plate V.

For level sections:

$$\text{Area} = (\text{Slope} \times \text{Cut or Fill} + \text{Base}) \times \text{Cut or Fill}$$

Slope, means side slopes of canals or embankment.

For 1 to 1 Slopes the value is 1

1.5 to 1 " " " " 1.5

2 to 1 " " " " 2 etc.

Cut or Fill, is the depth at the center line of the canal. or embankment.

Base, is the bottom width of canal or top width of embankment.

Example:- Let Slope = 1 to 1 = 1

Cut = 2.3′

Base = 8′

then Area = (1 x 2.3 + 8) x 2.3

= 10.3 x 2.3 = 23.69 sq. ft.

also let Slope = 1.5 to 1 = 1.5

Fill = 2.7

Base = 4′

then Area = (1.5 x 2.7 + 4) x 2.7

= (4.05 + 4)2.7 = 8.05 x 2.7 = 21.74 sq. ft.

The column headed "$\frac{1}{2}$ longer base" on Plate V is useful as it saves one calculation for each cut or fill area. The column is readily computed as follows:-

$$\frac{1}{2} \text{ longer base} = \frac{\text{Base}}{2} + \text{slope} \times \begin{matrix}\text{cut or}\\ \text{fill}\end{matrix}$$

All the terms here having the same meaning as in the formula for area just given.

Example:-

Let base = 8'

slope = 1 to 1 = 1

cut = 2.3'

Then $\frac{1}{2}$ longer base $= \frac{8}{2} + 1 \times 2.3 = 4 + 2.3 = 6.3$

It will be noticed by inspection of the formula just given and the Table, Plate V that the variation is constant. After computing the first two values the column may be completed by simply adding the increment of change successively.

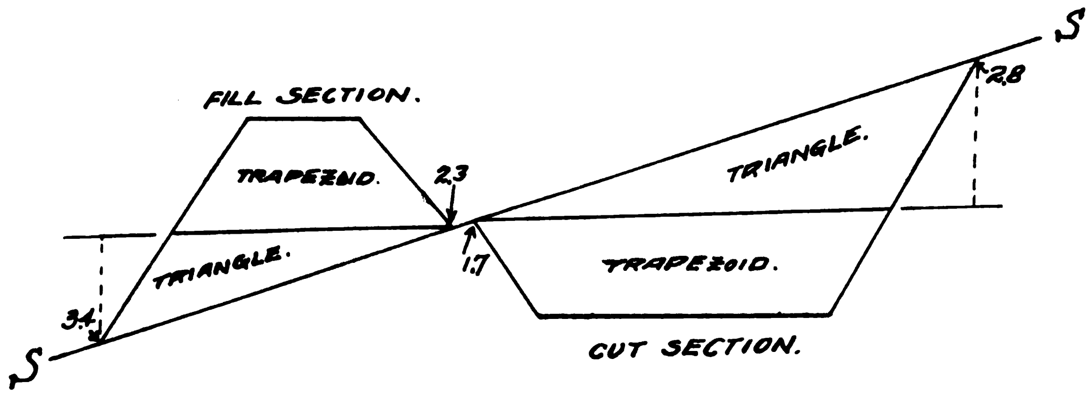
For practical use the tables must extend somewhat further than shown on Plate V which is simply illustrative. The extent of the table will, of course, be governed by the depth of the cuts and fills encountered in the location.

Having completed the tables, the next matter for consideration is the diagram on Plate VI. This is a drawing of the cross section of (FOR ILLUSTRATION) an 8' canal with a 4' bank other dimensions as shown, using a horizontal scale of

3 ft. = 1 in. and a vertical scale of 1 ft. = 1 in. This smaller horizontal scale is used so that the diagram will not be spread out over too great a space. The center lines and slope lines are then divided vertically into tenths of a foot, numbering every foot. Now referring to Plate IV, Columns 8 and 9 give the depth from the ground surface to the bottom of the canal on both the center line of the canal and the center line of the bank at any station. Laying off on their respective center lines on the diagram Plate VI any two corresponding values of cuts or fills and applying a straight edge through the points thus found will determine the ground line at this station; and where the straight edge intersects the slope lines will be the cuts and fills at these points.

For instance:- At Sta. 1, the cut at RT.12' (center line of fill) is 1.2 and at ℄c is 2.2'. Laying off these values on their respective center lines and passing the straight edge through these points gives the surface slope - the line SS on the diagram. This intersects the upper cut slope at 2.8 and the lower cut slope a little above 1.7; the inside fill slope at 2.3 plus and the outer fill slope at 3.4

We thus obtain a ditch section as shown in the sketch below:-



It will be evident that each of the areas may be divided by a horizontal line into a trapezoid and a triangle. In the case of the canal section, the altitude of the trapezoid is the smaller slope cut 1.7 and the altitude of the triangle is the difference in the two cuts 2.8 - 1.7 = 1.1 For the bank section, the altitude of the trapezoid is 2.3 and the altitude of the triangle is 3.4 - 2.3 = 1.1.

Entering the tables Plate with the smaller cut value 1.7 the area of the trapezoid is found to be 16.49 sq.ft. and the "½ longer base" is 5.7. Multipling "½ longer base" by the difference in the cuts, gives the area of the triangle which is, 5.7 x 1.1 = 6.27. Adding the two areas gives a total cut area of 22.76 sq. ft.

In the same manner the fill area is found to be 23.14 sq. ft.

The fill area being the greater, it represents the work required at this station and so the cut area is cancelled and not used further in the computations.

The cut and fill areas for each station being obtained after the manner above outlined and the smaller areas cancelled, the next step is to find the average or mean areas between stations. This is simply the operation of adding every two consecutive areas and dividing by two if the distance between stations is 100', or by 4 if the distance is 50', or by 8 if the distance is 25', or for any other distance d.

$$\text{Mean area} = \frac{\text{Area}_1 \quad \text{Area}_2}{2} \times \frac{d}{100}$$

After this the only remaining step is to sum the average areas for the various kinds of material and reduce to cubic yards by multiplying by $\frac{100}{27}$. An adding machine may here be utilized to great advantage, as the task of summing several hundred pages of notes is by no means a small one. PLATE VII SHOWS THE ABOVE OPERATIONS IN DETAIL.

2. ESTIMATE OF COST:

a. LOCAL PRICES:

In determining the unit costs of the various kinds of construction, careful inquiry should be made in regard to the prevailing local prices. Time spent in gathering all the information possible relative to similar work previously done in the locality may be considered a good investment. Consult the parties who have had work done rather than those who did it because the latter are liable to name prices which they would like to receive instead of those which they actually have received. However, sometimes an old experienced contractor can and will furnish reliable information which may be of great value in making up an estimate.

Reference may be had to books on Cost of Construction, but this at best is secondhand information and should be applied carefully and conservatively.

b. MANUFACTURED MATERIAL:

In ascertaining prices on manufactured materials such as concrete, steel and timbers, not only should the local dealers be consulted, but correspondence should be had with large jobbers at distant points.

Having obtained all possible information in regard to unit prices, the next step is to prepare outline specifications covering the whole system as comprehensively as possible. The aim should be to make concise rather than detailed statements in regard to the various structures. Of course, if time and funds will permit, a careful working out of all the particulars is desirable, but ordinarily this is not the case.

As far as possible the specifications should be clrar and to the point, free from indefinite or ambiguous clauses and not too heavily burdened with stereotyped stipulation "or to the satisfaction of the engineer in charge."

c. COPY OF ACTUAL SPECIFICATIONS:

Immediately following page 44 will be found a copy of an actual specifications and estimate of cost for a small irrigation system in Northern Colorado. This is not presented as a model set of specifications, but simply as illustrative of what has been found adequate in practice.

d. RELATIVE IMPORTANCE OF VARIOUS ITEMS:

With the specifications outlined and the quantities determined, each item of construction should be carefully considered with reference to its relative importance in the total cost. It would be folly to figure minutely the cost of a small headgate, bridge, or flume and make a rough guess at the unit prices of the earth and rock work. This may be clearly seen by examining the items in the actual specifications mentioned above. The total cubic yardage of earth work here given is nearly 380,000. A variation of one or two cents in the price per cubic yard would make a difference in the final result of from $4,000.00 to $8,000.00 a sum sufficient to construct several headgates, or other minor structures such as required on this system.

e. SUMMARY:

In tabulating the results and arriving at the total cost of construction, there is danger of some important items having been omitted. To avoid this possibility it is well to compare the list with a standard schedule of items that enter into the construction of a complete system. Such a list is given below:-

Abutments
Bridges
Basins, catch; still
Back - fill
Brick
Cement
Concrete
Canals
Clearing land
Conduits
Cuts
Chutes
Checks
Dams - reservoir, diversion
Drains
Drops
Earth - excavation, fill
Embankments
Engines

Forms
Flumes
Facing
Foundations
Gravel
Grubbing
Gauging flumes
Headgates
Iron
Inlet
Laterals
Lining
Lumber
Masonry work
Overflows
Outlet
Outlet tube
Pipe - Cast iron, wrot iron, steel, wooden, stone.

Pipe lines
Piles
Pumps
Retaining walls
Rip-rap
Rubble
Rock, solid; loose
Roads
Sand
Sheet piling
Sluices
Spillways
Syphons
Steel, reinforcing; beams
Tile
Trestles
Tunnels
Weirs
Wells
Walls

Having found the total cost of construction, there must be added a certain percentage - usually about 10% - to cover engineering and incidentals. Also an allowance must be made for the so-called overhead charges, such as, interest on bonds or other securities issued for construction purposes, organization expenses, legal fees and contingences. The above noted items may require a charge of from 20 to 50% over the actual cost of construction and if not taken into account may lead to financial ruin.

CONCLUSION.

In general it may be said that the two prime requisites for successful preliminary estimating are reasonable accuracy and speed in work. All legitimate means to these ends may well be considered good practice and a step forward in the art.

In striving to attain that degree of accuracy which seems compatible with the circumstances, the engineer should endeavor to figure on the safe side of all the items and favor an over rather than an under-estimate. It is much more pleasing to the owners and favorable to the engineer to have a snug sum left over and above the estimated cost than to be confronted in the end with a large overdraft. If the plans are changed or additional work called for after the estimate is completed, no charge can be made against the engineer on this account. The danger is not in this direction. It is the unknown or unexpected element, the accidentally omitted items that may suddenly loom up big and throw the estimate the wrong way. If possible the estimate should be checked over, even though roughly, by some entirely independent method.

Speed seems to be especially called for in preliminary work in order to save time and avoid expense. Until the estimate is completed, the feasibility of a project is not assured. All expense incurred is in the nature of a speculation.

The successful engineer in preliminary work is the one who can establish and maintain the proper balance between accuracy and rapidity. Herein lies the art of estimating, and experience is the best teacher.

The Graham Irrigation System.

Specifications and Estimate of Cost.

Specifications.

Inlet:

The inlet ditch extends from a point on the east bank of Muddy Creek to the Graham Reservoir, a distance of 28,533.0' or 5.4 miles.

The dimensions of the ditch are as follows:-

Bottom width: 20'.

Side slopes in both cut and fill: 1½ to 1.

Depth from top of bank to bottom of ditch: 6'.

Width of bank on top: 8'.

Depth of water: 5'.

Grade: .04 per 100 ft., or 2.11 ft. per mile.

Capacity: 388 cu. ft. per sec.

Embankments.

The ditch has a single bank, except at a few places where double banks are considered necessary.

There is a berme of 1 foot between the cut and the fill, and the surface of, the ground under the fill is to be corrugated parallel to the center line of the ditch, by plowing in furrows 6" deep and not over 18" apart.

The surface of the ground between fill stakes must be cleared of all coarse vegetation and loose rocks.

Excavation.

The excavation may be done by any method desired but the banks must be packed to the degree that would obtain by construction with scrapers or 4 horse fresnos.

Finish.

In the cuts, the finish will be that ordinarily used in canals of this size and for this purpose.

The cut must be left as smooth as practical without employing special machinery to finish it but the finished canal must have at all places sufficient cross-section to enable it to carry the specified quantity of water.

The embankments must be finished so as to have at least the specified side slopes.

Diversion Dam and Headgate in Muddy Creek.

The structure is to be of reinforced concrete, with steel headgates and collapsible spillway, similar in general to the diversion dam and headgates constructed at the head of the Empire Canal in Weld County, Colorado. (See Drawing.)

Excavation and Backfilling:

All excavation and backfilling for the structure shall be done by the contractor at his own expense and to the satisfaction of the engineer. Backfilling material must be wet and thoroughly tamped around the structures to insure a good joint to prevent leakage of water.

The dam shall be leveled in both directions and the floor shall be entirely in excavation.

The floor of the headgate shall be level with the floor of the dam.

Concrete:

The concrete shall be made as follows:- One part of sand to enough cement to fill the voids in the sand. Enough of this mixture to fill the voids in the gravel. The mixture to be what is known as "wet" mixture. Where there are forms, the gravel is to be spaded away from the forms so that the surface will be smooth when the forms are removed. All other surfaces must be left smooth and finished in a workmanlike manner.

Reinforcing:

Reinforcing shall be placed at the points indicated on the plans or as required by the engineer. The wire reinforcing may be of any kind that will give the same strength as a 4 inch square mesh of wires of a tensile strength of 1200# each. The bar reinforcing shall be of round bars of mild steel.

Wasteway at Potter Brown Creek.

The structure shall be of reinforced concrete, and of the automatic collapsible post type similar to the structure on the Moro Canal where it crosses Willow Creek. (See Drawing)

Specifications for Excavation and Backfilling, Concrete, Reinforcing, same as for headgate.

Reservoir.

Specifications for Dams.

Station 0 of centerline of the dams is at the southwest end.

Dimensions:

From Station 0 to 16.

Width of crest: 16 ft.

Inside slopes: 4 to 1.

Outside slopes: $2\frac{1}{2}$ to 1.

Height above high water line: 7 ft.

From Sta. 16 to Sta. 35.

Width of crest: 16 ft.

Inside slopes: $1\frac{1}{2}$ to 1.

Outside slopes: $2\frac{1}{2}$ to 1.

Height of earth embankment above High water line: 5 ft.

From Sta. 35 to 55 50.

Width of crest: 16 ft.

Inside slopes: 4 to 1.

Outside slopes: $2\frac{1}{2}$ to 1.

Height above high water line: 7 ft.

Concrete facing.

From station 16 to station 35 the inside face of the dam is to be covered with a continuous slab of reinforced concrete 4 inches thick. The concrete is to be made according to the specifications for concrete as given in connection with the diversion dam and headgate.

The reinforcing to be of one thickness of galvanized wire fabric with 4 inch square meshes of wires of tensile strength of at least 1200#. This reinforcing to be placed near the center of the concrete slab.

The edges of the wire reinforcing shall be lapped two inches or otherwise as the engineer may direct.

At the crest of the dam (Sta. 16 to 35) there shall be a 6 inch coping wall two feet in height above the earth fill, and joined to the concrete facing, and reinforced in the same manner.

Earthwork.

Earth will be put in the dam in level layers not exceeding 3 feet in thickness by means of dump wagons or by some method that will leave the material equally compact.

Only the best material within a reasonable limit of haul will be permitted in the dam.

On the inside surface of the dam, the material shall be thoroughly wetted as it is put on, to a depth of 12 feet measured at right angles to the finished surface of the dam. This wet slab is to form a firm foundation for the concrete face.

Preparation of Base of Dam.

From the center of the dam to the outer stakes the ground shall be thoroughly plowed to a depth of 10 inches If there is any brush or grass on the surface of the ground, it must be removed beyond the base of the dam before any plowing is done.

From the inner half of the dam the surface of the ground will be removed for a depth of 10 inches. This material may be used near the outer toe.

Then the inner half of the dam will be corrugated in furrows 10" deep and 2 ft. apart from inside to outside of furrow; these furrows to run parallel to the center line of the dam.

Borrow Pits:

Borrow pits may be made on either side of the dam. A berme of 50 ft. must be left between the inside edge of the pits and the cross section stakes of the dam.

Capacity of Reservoir: 4815.0 Ac. Ft.

Depth of Water: 37.5 ft.

Outlet.

The outlet consists of a main canal and two branch laterals, Lateral A, and Lateral B.

The main canal begins at the end of the flume across the Byon Creek and extends northwesterly a distance of 19,800 ft. or 3.7 miles. At this point it divides into two laterals, one, Lateral A going west and then north along the side of a road a distance of 1.9 miles; the other, Lateral B going N.E. on the east side of Antelope Creek a distance of one mile.

The specifications for the earthwork on the outlet canal and laterals are the same as for the inlet.

Main Canal.

Dimensions:

From Sta. 25 to Sta. 173.

Bottom width: 8 ft.

Side slopes in cut and fill: 1½ to 1.

Depth from top of bank to bottom of ditch: 3.5 ft.

Width of bank on top: 6 ft.

Depth of water: 2.5 ft.

Grade: .05 per 100 ft. or 2.64 ft. per mile.

Capacity: 53.0 cu. ft. per sec.

From Sta. 173 to Sta. 223.

Bottom width: 8 ft.

Side slopes in cut: 1 to 1.

Side slopes in fill and embankment: 1½ to 1.

Depth from top of bank to bottom of ditch: 3.5 ft.

Width of top of bank: 6 ft.

Depth of water: 2.5 ft.

Grade: .06 per 100 ft. or 3.17 ft. per mile.

Capacity: 53.0 cu. ft. per sec.

The ditch has double banks throughout most of its length.

Lateral A.

Dimensions:

From Sta. 0 (223 on main canal) to Sta. 31 (Sta. 31 equals 0 along road).

Bottom width: 5 ft.

Upper cut slope: 1 to 1.

Lower cut and embankment slopes: 1½ to 1.

Width of bank on top: 4 ft.

Depth from top of bank to bottom of ditch: 3 ft.

Depth of water: 2 ft.

Grade: .08 per 100 ft. or 4.22 ft. per mile.

Capacity: 28.0 cu. ft. per sec.

Single bank.

From Sta. 30 to 11 80 (along road).

Bottom width: 5 ft.

Side slopes, both cut and fill: 1½ to 1.

Width of bank on top: 4 ft.

Depth from top of bank to bottom of ditch: 2.8 ft.

Depth of water: 1.8 ft.

Grade: 0.1 per 100 ft. or 5.28 ft. per mile.

Capacity: 28.0 cu. ft. per sec.

Double banks.

From Sta. 11 80 to Sta. 40.

Bottom width: 4 ft.

Side slopes, both cut and fill: 1½ to 1.

Width of bank on top: 4 ft.

Depth from top of bank to bottom of ditch: 2.8 ft.

Depth of water: 1.8 ft.

Grade: 0.25 per 100 ft. or 12.20 ft. per mile.

Capacity: 28.0 cu. ft. per sec.

Double banks.

From Sta. 40 to Sta. 80.

Dimensions same as for ditch from Sta. 30 to 11 80.

Lateral B.

Dimensions.

Station 0 (223 of main canal) to Station 52.

Bottom width: 4 ft.

Side slopes, both cut and fill: $1\frac{1}{2}$ to 1.

Width of banks on top: 4 ft.

Depth from top of bank to bottom of ditch: 2.5 ft.

Depth of water: 1.5 ft.

Grade: 0.2 per 100 ft. or 10.56 ft. per mile.

Capacity: 25.0 cu. ft. per sec.

Double banks.

Flumes.

1st. Flume across Bijou.

From Sta. 6 25 to Sta. 25 50 (main canal)

Height of sides: 2 ft.

Width of bottom, inside: 3 ft. 3 in.

Grade: 0.2 per 100 ft.

Length: 1925 ft.

Capacity: 53 sec. ft.

2nd. Flume across Antelope.

From Sta. 13 to 20. Lateral A.

Height of sides: 2 ft.

Width of bottom, inside: 2 ft. 6 in.

Grade: 0.25 per 100 ft.

Length: 700 ft.

Capacity: 28 sec. ft.

Estimate of Cost.

Inlet Ditch.		
Headgate in Muddy Creek	$2000.00	
Wasteway at Potter Brown Creek,	500.00	
Bridges, 4 @ $250.00	1000.00	
Earthwork; 104,091.0 cu.yds. @ 15¢	15613.65	
		$19,113.65
Reservoir Dams.		
Earthwork; 233,454.0 cu.yds. @ 18¢	42021.72	
Facing; 1500 cu.yds. @ $12.	18000.00	
		60,021.72
Outlet Ditch.		
Headgate in Reservoir;	1000.00	
Outlet cut 3300 cu.yds @ 20¢	660.00	
Outlet Pipe 300 ft. @ 6.00	1800.00	
Flume across Bijou 1925 @ $225.00	4331.25	
" " Antelope 700 @ $200.00	1400.00	
Earthwork, main canal; 25,862.0 cu.yds. @ 12¢	3103.44	
Lateral A. 9,866.8 Cu.yds. @ 12¢	1184.02	
Lateral B. 3,366.3 cu.yds. @ 12¢	403.96	
		13,882.67
		$93,018.04
Plus 10% for Engineering and Incidentals		9,301.80
		$102,319.84

EXAMPLE SHOWING USE OF KUTTER'S FORMULA.

THE STANDARD HYDRAULIC FORMULA FOR FLOW IN OPEN CHANNELS IS:— $V = C\sqrt{R \times S}$

WHERE V = VELOCITY IN FT. PER SEC.

R = HYDRAULIC OR MEAN RADIUS.

$= \dfrac{\text{AREA OF WET CROSS-SECTION} = A}{\text{LENGTH OF WET PERIMETER} = p}$

S = GRADE OR SLOPE PER FT.

C = COEF. EVALUATED BY KUTTER'S FORMULA, VIZ:—

$$= \frac{41.6 + \frac{.00281}{S} + \frac{1.811}{n}}{1 + \frac{\left(41.6 + \frac{.00281}{S}\right) \times n}{\sqrt{R}}}$$

WHERE n = COEF. OF ROUGHNESS.

THE FORMULA FOR DISCHARGE IS, $Q = \dfrac{A = \text{WET CROSS-SECTION}}{V = \text{VELOCITY}}$

ASSUME THE FOLLOWING GIVEN CONDITIONS:—

Q = 75 SEC. FT. REQUIRED DISCHARGE OR CAPACITY OF CANAL.

V = 2.6 FT. PER SEC. PERMISSIBLE VELOCITY.

n = .026 B = 8 FT. = BOTTOM WIDTH OF CANAL.

SIDE SLOPES 1 TO 1.

TO FIND THE DEPTH OF WATER AND SLOPE, S.

IN ORDER TO SOLVE THIS PROBLEM IT IS NECESSARY TO ASSUME A TRIAL GRADE OR SLOPE. LET $S = .001$ FT. PER FT. = 0.1 PER 100 FT.

THEN:— $Q = \frac{A}{V}$ OR $A = \frac{Q}{V} = \frac{75}{2.6} = 28.8$ SQ. FT. AREA OF WET SECTION.

FROM THE TABLE PLATE V WE GET A CUT OR DEPTH OF 2.7 FT. NEARLY, CORRESPONDING TO THIS AREA.

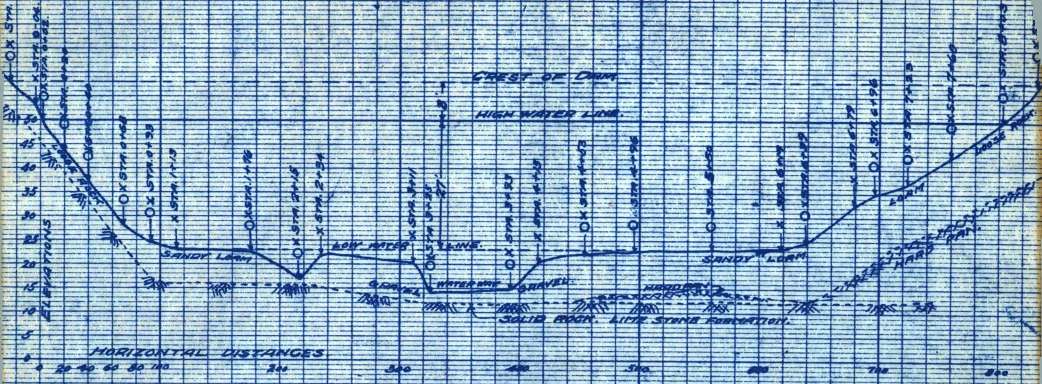
THEN $R = \frac{A}{p} = \frac{28.8}{8 + 2.7 \times 2 \times 1.414} = \frac{28.8}{15.6} = 1.85$

AND $$C = \frac{41.6 + \frac{.00281}{.001} + \frac{1.811}{.026}}{1 + \frac{\left(41.6 + \frac{.00281}{.001}\right).026}{\sqrt{1.85}}} = 61.7$$

$\therefore V = 61.7\sqrt{1.85 \times .001} = 2.64$ FT. PER SEC.

THIS VELOCITY IS NEAR ENOUGH FOR PRACTICAL PURPOSES TO THE ASSUMMED VELOCITY, WHICH SHOWS THAT THE TRIAL SLOPE IS ABOUT CORRECT.

PLATE II.



PROFILE OF RESERVOIR DAM SITE ON CENTERLINE

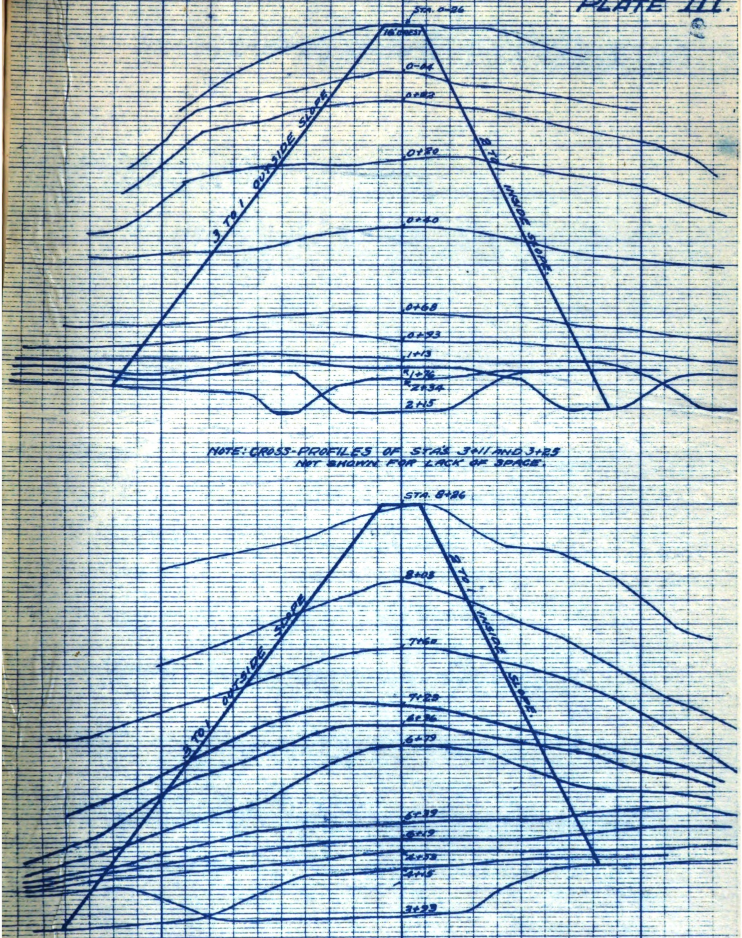
SHOWING SURFACE AND SUBSOIL FORMATION.

SCALE { BETWEEN VERTICAL LINES = 20 FEET. (HORIZONTAL DISTANCES) / BETWEEN HORIZONTAL LINES = 1 FOOT. (ELEVATIONS)

X = CROSS PROFILES.

O = TEST HOLES

PLATE III.



CROSS-PROFILES OF RESERVOIR DAM SITE AND SECTION OF DAM.

SCALE { BETWEEN VERTICAL LINES = 10 FEET.

PLATE IV.

STA.	B.S.	H.I. AND ELEV. OF SURF. RT. 12'	F.S. RT. 12'	F.S. ℄C	℄C ELEV. OF SURFACE	ELEV. OF GRADE	CUT OR FILL RT. 12'	CUT OR FILL ℄C.	FILL AREA.	CUT AREA.	AVG. AREA.	REMARKS.	
B.M.	3.33	105.73			102.40							ON W.O. STUMP	
0		101.73	4.0	4.0	101.73	100.00	1.73	1.73	17.14	16.49		RT. 60' STA. 0+20	
1		101.1	4.6	3.6	102.1	99.9	1.2	2.2	23.14	~~22.76~~	20.28	S.B. 0 —	
2		101.7	4.0	2.4	102.3	99.8	1.9	2.5	~~15.45~~	26.78	24.96	E. 0 —	
+50		101.6	4.1	3.3	102.4	99.75	1.8	2.6	~~16.42~~	28.02	13.70		
3		101.0	4.7	4.0	101.7	99.7	1.3	2.0	~~20.48~~	22.16	12.55		
4		101.2	4.5	3.6	102.1	99.6	1.6	2.5	~~18.50~~	26.00	24.08		
T.P.	4.08	106.31		3.50	102.23								
4+50		100.2	6.1	5.2	101.1	99.55	0.6	1.5	31.20	~~14.09~~	14.30		
5		99.2	7.1	5.6	100.7	99.5	-0.3	1.2	45.85	~~11.14~~	19.26	L.R. 5 —	
5+50		100.4	5.9	5.2	101.1	99.45	0.9	1.6	26.58	~~15.80~~	18.11		
6		100.5	5.8	5.0	101.3	99.4	1.1	1.9	24.56	~~18.65~~	12.78	R. 6 —	
+25		100.7	5.6	5.1	101.2	99.38	1.3	1.8	22.26	~~17.60~~	5.85		
+50		100.5	5.8	5.4	100.9	99.35	1.0	1.5	25.37	~~14.21~~	5.95		
+75		100.4	5.9	5.0	101.3	99.33	1.1	2.0	24.50	~~20.40~~	6.23		
7		101.0	5.3	4.5	101.8	99.3	1.7	2.5	17.50	26.70	6.40	L.R. 7 —	
+50		100.7	5.4	4.8	101.5	99.25	1.5	2.2	19.77	22.94	12.41		
8		101.2	5.7	5.0	101.3	99.2	2.0	2.1	14.00	21.20	11.04	E 8 —	
9		100.9	5.4	5.1	101.2	99.1	1.8	2.1	16.62	21.80	21.50		
10		101.3	5.0	5.0	101.3	99.0	2.3	2.3	22.20	23.69	23.74	D.B. 10 —	
B.M.10	4.37	105.00		5.00	100.63							ON PINE STUMP	
11		101.3	3.7	3.8	101.2	98.9	2.4	2.3	20.30	23.69	23.69	LT. 50' STA. 9+50	
12		101.4	3.6	4.0	101.0	98.8	2.6	2.2	24.53	22.44	24.11		
13		100.8	4.6	4.0	101.0	98.7	2.1	2.3	22.00	23.68	24.11		CU. YDS.
										EARTH	245.28 × 100/27 =		908.4
										LOOSE ROCK	56.34 × 100/27 =		211.3
										ROCK	24.43 × 100/27 =		90.5

(Marginal sums beside AVG. AREA column: 3089; 2443; 2345)

ABBREVIATIONS:— RT. 12' = 12 FT. ON RIGHT SIDE OF CENTERLINE FACING DOWNSTREAM. ℄C = CENTERLINE OF CANAL. W.O. = WHITE OAK. S.B. 0— = SINGLE BANK FROM HERE (STA. 0.) ON. D.B. 10— = DOUBLE BANKS FROM HERE (STA. 10) ON. E. 0— = EARTH FROM HERE (STA. 0.) ON. L.R. 5 — = LOOSE ROCK FROM HERE (STA. 5) ON. R. 6— = SOLID ROCK FROM HERE (STA. 6) ON (TO NEXT CLASSIFICATION).

PLATE IV.

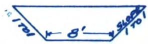
COL. 1.	2.	3.	4.	5.	6.	7.	8	9	10	11	12	13
1. STA.	B.S.	H.I. AND ELEV. OF SURF. RT. 12	F.S. RT. 12	F.S. ℄C	℄C ELEV. OF SURFACE	ELEV. OF GRADE	CUT OR FILL RT. 12	CUT OR FILL ℄C.	FILL AREA.	CUT. AREA.	AVG. AREA.	REMARKS. 1A.
B.M.	3.33	105.73			102.40							ON W.O. STUMP
0		101.73	4.0	4.0	101.73	100.00	1.73	1.73	17.14	~~16.49~~		RT. 60' STA. 0+20
1		101.1	4.6	3.6	102.1	99.9	1.2	2.2	23.14	~~22.76~~	20.28	S.B. 0 —
2		101.7	4.0	2.4	102.3	99.8	1.9	2.5	~~15.45~~	26.78	24.96	E. 0 —
+50		101.6	4.1	3.3	102.4	99.75	1.8	2.6	~~16.42~~	28.02	13.70	
3		101.0	4.7	4.0	101.7	99.7	1.3	2.0	~~20.48~~	22.16	12.55	
4		101.2	4.5	3.6	102.1	99.6	1.6	2.5	~~18.50~~	26.00	24.08	
T.P.	4.08	106.31	3.50		102.23							
4+50		100.2	6.1	5.2	101.1	99.55	0.6	1.5	31.20	~~14.09~~	14.30	
5		99.2	7.1	5.6	100.7	99.5	-0.3	1.2	45.85	~~11.14~~	19.26	L.R. 5 —
5+50		100.4	5.9	5.2	101.1	99.45	0.9	1.6	26.58	~~15.80~~	18.11	
6		100.5	5.8	5.0	101.3	99.4	1.1	1.9	24.56	~~18.65~~	12.78	R. 6 —
+25		100.7	5.6	5.1	101.2	99.38	1.3	1.8	22.26	~~17.60~~	5.85	
+50		100.5	5.8	5.4	100.9	99.35	1.0	1.5	25.37	~~14.21~~	5.95	
+75		100.4	5.9	5.0	101.3	99.33	1.1	2.0	24.50	~~20.40~~	6.23	
7		101.0	5.3	4.5	101.8	99.3	1.7	2.5	~~17.50~~	26.70	6.40	L.R. 7 —
+50		100.7	5.4	4.8	101.5	99.25	1.5	2.2	~~19.77~~	22.94	12.41	
8		101.2	5.1	5.0	101.3	99.2	2.0	2.1	~~14.00~~	21.20	11.04	E 8 —
9		100.9	5.4	5.1	101.2	99.1	1.8	2.1	~~16.57~~	21.80	21.50	
10		101.3	5.0	5.0	101.3	99.0	2.3	2.3	~~22.28~~	23.69	22.74	D.B. 10 —
B.M.TR	4.37	105.00	5.68		100.63							ON PINE STUMP
11		101.3	3.7	3.8	101.2	98.9	2.4	2.3	~~22.30~~	23.69	23.69	LT. 50' STA. 9+50
12		101.4	3.6	4.0	101.0	98.8	2.6	2.2	24.53	~~22.40~~	24.11	
13		100.8	4.2	4.0	101.0	98.7	2.1	2.3	~~22.80~~	23.68	24.11	CU. YDS.
										EARTH	245.28 $\times \frac{100}{27}$ =	908.4
										LOOSE ROCK	54.34 $\times \frac{100}{27}$ =	201.3
										ROCK.	24.43 $\times \frac{100}{27}$ =	90.5

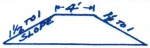
(Marginal sums beside col. 12: 30.89; 24.43; 23.45)

ABBREVIATIONS:— RT. 12' = 12 FT. ON RIGHT SIDE OF CENTERLINE FACING DOWN GRADE. ℄C = CENTERLINE OF CANAL. W.O. = WHITE OAK. S.B. 0 — = SINGLE BANK FROM HERE (STA. 0.) ON. D.B. 10 — = DOUBLE BANKS FROM HERE (STA. 10.) ON. E. 0 — = EARTH FROM HERE (STA. 0.) ON. L.R. 5 — = LOOSE ROCK FROM HERE (STA. 5.) ON. R. 6 — = SOLID ROCK FROM HERE (STA. 6.) ON (TO NEXT CLASSIFICATION).

AREA = [CUT OR FILL x SLOPE + BASE] x CUT OR FILL.

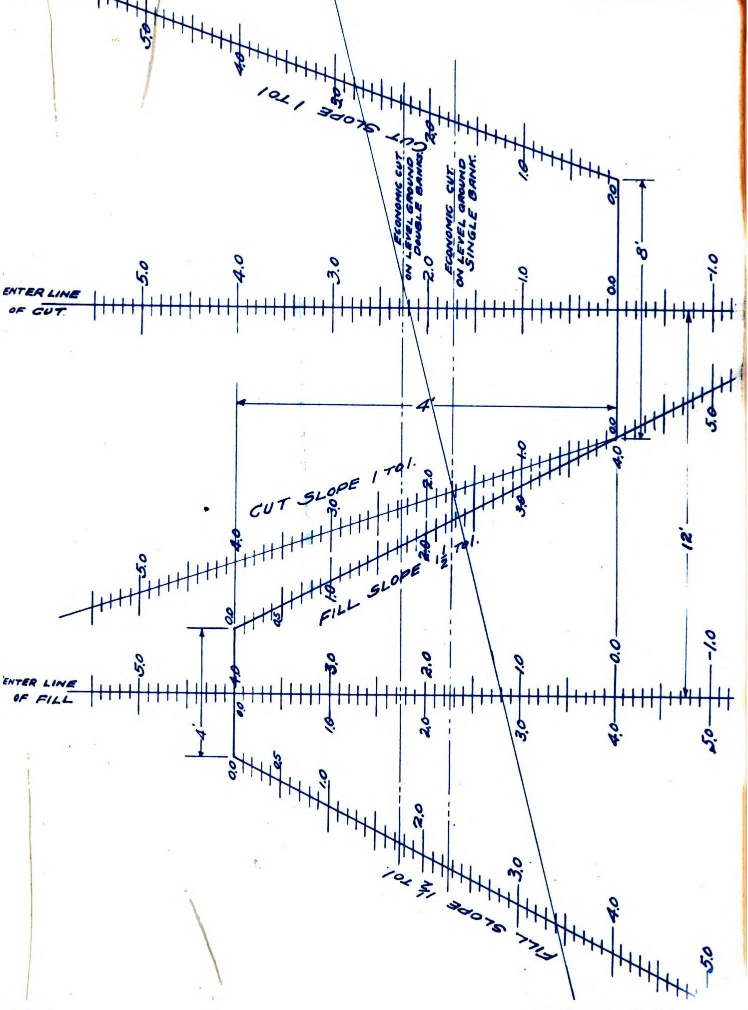
$\frac{1}{2}$ LONGER BASE = $\frac{BASE}{2}$ + CUT OR FILL x SLOPE.

CUT


FILL


CUT	AREA	½ LONGER BASE	FILL	AREA	½ LONGER BASE
0.0	0.0	0.0	0.0	0.0	0.0
.1	0.81	4.1	.1	.42	2.15
.2	1.64	4.2	.2	.86	2.30
.3	2.49	4.3	.3	1.34	2.45
.4	3.36	4.4	.4	1.84	2.60
.5	4.25	4.5	.5	2.38	2.75
.6	5.16	4.6	.6	2.94	2.90
.7	6.09	4.7	.7	3.54	3.05
.8	7.04	4.8	.8	4.16	3.20
.9	8.01	4.9	.9	4.82	3.35
1.0	9.00	5.0	1.0	5.50	3.50
.1	10.01	5.1	.1	6.22	3.65
.2	11.04	5.2	.2	6.96	3.80
.3	12.09	5.3	.3	7.74	3.95
.4	13.16	5.4	.4	8.54	4.10
.5	14.25	5.5	.5	9.38	4.25
.6	15.36	5.6	.6	10.24	4.40
.7	16.49	5.7	.7	11.14	4.55
.8	17.64	5.8	.8	12.06	4.70
.9	18.81	5.9	.9	13.02	4.85
2.0	20.00	6.0	2.0	14.00	5.00
.1	21.21	6.1	.1	15.02	5.15
.2	22.44	6.2	.2	16.06	5.30
.3	23.69	6.3	.3	17.14	5.45
.4	24.96	6.4	.4	18.24	5.60
.5	26.25	6.5	.5	19.38	5.75
.6	27.56	6.6	.6	20.54	5.90
.7	28.89	6.7	.7	21.74	6.05
.8	30.24	6.8	.8	22.96	6.20
.9	31.64	6.9	.9	24.22	6.35
3.0	33.00	7.0	3.0	25.50	6.50
.1	34.41	7.1	.1	26.82	6.65
.2	35.84	7.2	.2	28.16	6.80
.3	37.29	7.3	.3	29.53	6.95
.4	38.76	7.4	.4	30.94	7.10

PLATE VI.


ENTER LINE
OF CUT
ENTER LINE
OF FILL
CUT SLOPE 1 TO 1
ECONOMIC CUT
ON LEVEL GROUND
DOUBLE BANK.
ECONOMIC CUT
ON LEVEL GROUND
SINGLE BANK.
8'
4'
12'
4'
CUT SLOPE 1 TO 1.
FILL SLOPE 1½ TO 1.
FILL SLOPE 1½ TO 1

REDUCTION OF NOTES ON PLATE IV.

STATION	EMBANKMENT.	EXCAVATION.
0	SEE COL. 3 (PLATE IV) 105.73 " " 4 − 4.00 " " 3 101.73 " " 7 − 100.00 " " 8 1.73 A CUT OF 1.73 GIVES A FILL OF 4′(DEPTH OF CANAL) − 1.73′ = 2.3′ FROM PLATE V A FILL OF 2.3 GIVES AN AREA = 17.14	SEE COL. 3 105.73 " " 5 − 4.00 " " 6 101.73 " " 7 − 100.00 " " 9 1.73 FROM PLATE V A CUT OF 1.7′ GIVES AN AREA = ~~16.49~~
1.	SEE COL. 3 105.73 " " 4 − 4.60 " " 3 101.1 " " 7 − 99.9 " " 8 1.2	SEE COL. 3 105.73 " " 5 − 3.6 " " 6 102.1 " " 7 99.9 " " 9 2.2
	USING THESE VALUES 1.2 AND 2.3. ON THE CENTERLINES ON DIAGRAM PLATE VI AND APPLYING STRAIGHT EDGE (LINE SS) GIVES:—	
	FILLS = 3.4 AND 2.3 DIFFERENCE IN FILLS = 1.1	CUTS = 2.8 AND 1.7 DIFFERENCE IN CUTS = 1.1
	FROM TABLES PLATE V	
	FILL 2.3 GIVES AREA = 17.14. 1.1 × 5.45 = 6.00 ∴ TOTAL FILL AREA = 23.14	CUT 1.7 GIVES AREA = 16.49 1.1 × 5.7 = 6.27 ∴ TOTAL CUT AREA = ~~22.76~~
2	SAME PROCEEDURE AS ABOVE GIVES:— FILL AREA = ~~15.45~~	CUT AREA = 26.78
2+50	FILL AREA = ~~16.42~~	FILL AREA = 28.02

AVERAGE AREAS. (COL 12)
(USING ONLY LARGER VALUES IN COLS. 10+11)

$$\frac{17.14 + 23.14}{2} = 20.28$$

$$\frac{23.14 + 26.78}{2} = 24.96$$

$$\frac{26.78 + 28.02}{4} = 13.70$$

$$58.94 \times \frac{100}{27} = 218.3 \text{ CU. YDS.}$$

FROM STA. 0 TO 2+50

ROOM USE ONLY

Mar 25 '35