PROBLEMS ENCOUNTERED IN LOCATION, DESIGN, AND CONSTRUCTION OF OPEN DRAINAGE DITCHES

By H. C. Morrison, Gibson County Engineer

In order that a drainage project may be economically constructed and accomplish the purpose for which it was designed, the drainage engineer should consider the following very fundamental data and hydraulic principles: (a) location of drains; (b) precipitation; (c) flood run-off; (d) stream discharge measurements; (e) flow of water in open channels; (f) construction details.

Location of Drains

In the location of open drainage ditches, the first consideration should be the outlet. Usually there is but one choice; that is, but one river or stream in which to discharge the water, although in some instances new outlets can be made and distance shortened by cutting through some ridge to a new outlet with a resulting increased fall. After the approximate outlet is located, a study should be made by surveys and reconnoitering so as to determine the physical conditions of the area to be drained, as follows:

First, the boundaries and area of the water shed should be determined.

Second, the various existing water courses, sloughs, ponds, and bayous should be located and their sizes determined, in order to decide as to the advisability of following any parts of the existing water courses with the new channel, and whether storage capacity is available and desirable in the ponds and sloughs.

Third, the location of the railroads, highways, and existing drainage structures should be considered carefully so as to determine how least to disturb or damage them and still accomplish the best and cheapest drainage. Often new crossings of railroads and highways are desirable from a drainage standpoint, but from a matter of policy it may be better to use the old ones. It is reasonable to assume that drainage is needed whenever a drainage petition is docketed, and it is the duty of the engineer to use every honorable effort to aid the movement.

Fourth, the location of buildings and towns within the area should be considered. If there is a town or city of considerable size which discharges into the drainage system, then the run-off from that portion of the district will have a larger drainage co-efficient because of the improved streets, curbs and gutters, and sewer systems.

Fifth, the amount of land in cultivation, pasture land, swamps, and forests should be determined as these all have a determining influence on the run-off.

The relative elevations of the various parts of the watershed should be definitely determined. A contour map is desirable, but often the engineer, especially if he be the county engineer, has so many other duties that his time may be too limited to prepare one. If topographic maps published by the U. S. G. S. are available for the district, the necessary data from these will take the place of a special contour map prepared for the district. If a contour map is prepared, much time may be saved in reconnoitering later.

After the physical conditions have been examined as above suggested and an outlet has been determined upon, then the main ditch should be located. If the area is flat, then some choice may be exercised as to the location of the main, but it should be near the major axis of the drainage area and, if possible, along the section or land lines. Quite often it becomes necessary to cut diagonally across tracts of land, much to the grief of the landowner and to the annoyance of the engineer. A dissatisfied landowner and a hungry lawyer can often picture to a court a perfectly drained forty-acre tract lying in the middle of the lowest depression in a drainage area and intimate the incompetency of the drainage engineers grown gray in the profession.

One must look beyond the boundaries of any one landowner in the location of the main ditch, consider the value and life of the drainage project, and not let it be impaired by the whims of some narrowminded landowner. The law provides for damages to be paid to any landowner if damaged and adjustments can sometimes be made in this way. Often a little persuasion and reasoning will cause an obstinate landowner to acquiesce in a perfectly good alignment although his land is diagonally cut.

If the flooded area is narrow, the old channel can frequently be used to advantage, not so much for the saving of the yardage (as the contractors usually prefer solid cutting to crossing and re-crossing old channels) but for the fact that less land is damaged by using it. However, if the channel is small, in a few years it can be filled and cultivated.

If the valley is small, then the location of the main may be more difficult along section or land lines for any considerable distance, as it is only by chance that the valleys follow the cardinal points for any considerable distance. Submains and laterals are located in the same way and along the trend of the various natural drains.

The ditches should all be as straight as possible so as to obtain the maximum fall available and also to secure increased velocity of flow. Wherever it is necessary to use curves, they should be limited to from 4 to 20 degrees. Where a high velocity is expected, as flat a curve as is consistent with local conditions should be used. Erosion is more likely to occur at the ends of a curve, and this tendency can be reduced by using a short easement curve.

Design

In passing to the discussion of the design of ditches, the first thing to be considered is the precipitation for the district. If run-off data were available for all watersheds, there would be no particular need for precipitation records. Unfortunately, records of run-off are available for comparatively few watersheds and these for short periods of time only. The engineer is compelled, therefore, to estimate the run-off largely from his knowledge of the precipitation. While there is no definite ratio of general application between rainfall and run-off, yet the latter is dependent on the former. A knowledge of precipitation, its amount, occurrence, and distribution, therefore, are of primary importance in flood control and drainage work.

For many years, the Department of Agriculture has maintained weather bureau stations all over the country, of which there are about 4700. These stations are equipped with necessary recording instruments. Quite a few have automatic recording devices which give a continuous record of precipitation, being the only ones at which the precipitation during short periods of time is recorded. Most of the stations keep only the daily records. The value of the automatic readings lies in the fact that it gives data as to the intensity of rainfall over various periods. However, by a study of the daily rainfall one may obtain maximum and average rainfalls.

While at particular stations there are periods of low rainfall followed by periods of high rainfall, the lengths of these periods are very irregular and do not follow any definite law. The amount of rainfall in any year is more a matter of chance than the result of a well-defined law.

After the precipitation records have been studied, then the question presents itself of just how much will run off. By run-off we mean that portion of the rainfall which finds its way into natural or artificial channels, either as surface flow during a storm period or as subsurface flow after the storm period has passed. Flood run-off is expressed in three ways: by the number of cubic feet of discharge per second, by the cubic feet discharge per second per square mile of area, or by the depth in inches over the entire area for a period of twenty-four hours. If expressed by the last method, it is called the drainage modulus. An inch modulus is equivalent to 26.88 cubic feet of run-off per second per square mile of area.

The run-off can be determined by stream gaging; but seldom do we have stream gaging data on the streams in question, and when the engineer is called upon the time available is too short to make much of a study of gaging. However, some idea can be obtained if gagings are made over short periods. A comparison of the area in consideration must then be made with other districts of known area and similar characteristics. The Government publishes a number of circulars on pumping stations in operation in various parts of the United States which give complete records of the amounts of run-off pumped daily and the amounts of rainfall. Also any good textbook on drainage and flood control will give similar data. By a study of these, a suitable drainage modulus can be determined for the area in question.

Flow of Water in Open Channels

This is a subject which could be discussed at length, and is one which is all important in designing a drainage system which will be adequate. The velocity formulae are all based largely on the law of gravitation, as it is that force which causes the water to flow, but there are several influences which otherwise affect velocities. The surface slope of the drain is determined in the ordinary way, by use of the level. In designing channels, a slope formula is used in which the velocity computed is the mean velocity in the cross-section. The depth of the flow in the channel has an effect on the velocity; the deeper the flow, the greater the velocity, as the frictional resistance is decreased when a greater depth is obtained. Hence, the hydraulic radius of a stream, that is, the area of the channel section divided by the wetted perimeter, is an element to consider in the design of a ditch.

The channel resistance may be due to many things, such as the material forming the channel, irregularity of bottom and banks, changes in size and shape of cross-section, weeds, and growth of various kinds, logs, snags, and other obstructions. But in considering a new channel, the shape of the cross-section and the kind of soil formation would probably be the only items to consider.

There are a number of formulae by which the velocity of flow may be calculated, but the one generally used is a combination of Chezy's and Kutter's. Chezy's formation is $V = c\sqrt{rs}$, where

V is the mean velocity in feet per second,
r is the hydraulic radius,
s is the slope or fall per foot,

and c is a varying co-efficient embracing all the retarding influences other than r and s.

In Kutter's Formula, a value for c is found when the proper values are substituted for the various element in the formula.

After a drainage modulus is chosen, the quantity of water required to be carried by the ditch may be obtained. The speaker has obtained very satisfactory results in ditches constructed in southwestern Indiana by the use of a drainage modulus of 1 to 1½ inches for drains of smaller areas, and of ½ inch for the districts having areas of 150 to 250 square miles.

Then, by the application of the formula,

$Q = AV$,

where

Q = the quantity of discharge in cubic feet per second,

A = the area of the channel cross-section in square feet, and

V = the velocity in feet per second,

using a trial cross-section, we may determine the size of the channel needed for any particular district under consideration. For example, consider an area of 40 square miles and a drainage modulus of 1 inch, then

$Q = 40 \times 26.88 = 1075.2$ cubic feet per second required to be discharged by the ditch.

Assume a ditch with 12 feet base 12 feet deep, with slope of banks 1:1, and with a surface slope of 1.85 feet per mile or a slope per foot of .00035, assuming the co-efficient of roughness (n) to be .025 which is the usual value assigned to drainage ditches in good condition. Then $A = 288$; p, the wetted perimeter, is 46, and the hydraulic radius, r, is 6.2. This will give a velocity using the Chezy-Kutter formula of 3.8 feet per second. Then substituting in the formula $Q = AV$, we have

$Q = 288 \times 3.8 = 1094$ cubic feet per second, which compares favorably with the results desired above of 1075.2.

Construction Details

In the consideration of construction details, the average ditch presents no difficulties, but sometimes the unexpected may happen. The soil conditions on most projects vary within the district. The sides may stand up well until some new or different formation is encountered; then suddenly they will give away, and will not stand at all with the same slopes.

If a dragline machine or floater is used, the machine should be moved back as soon as possible and the deposits removed if they be of such an extent as to be damaging to the project. Unfortunately, no provision is made in the law so that extra pay may be made above the contract price, but oftentimes it seems that the contractor should be reimbursed for work done on account of unavoidable and unforeseen conditions about which the engineer or contractor has no advance knowledge. In one instance, the speaker had the experience of the bottom of the ditch bulging up near the center, considerably above grade, in which case the drainage system would have been materially damaged. The contractor moved back, however, and not only removed the dirt in the bottom, but also moved some of the spoil banks farther from the edges so as to relieve the pressure. In this case, however, the matter was presented to the court and a special order made to reimburse the contractor. In most cases the contractor performs such extra work without pay.

Sometimes, one of the biggest problems to contend with in the construction is the disposition of the landowners and the willingness of the commissioner of construction to change the specifications to meet their wishes and whims. Changes often can be made to advantage, but one is treading on dangerous grounds to do so, as he is violating the order of the court, and unless there is every reason to believe that everybody concerned would be benefited thereby, it is not policy to make changes.

ADEQUATE WATERWAYS FOR CULVERTS AND BRIDGES

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Adequate drainage means that certain factors of maintenance will be reduced to a minimum. It has even been said, and with much truth, that the entire problem of ordinary country road improvement and maintenance is one of drainage. The stability of the whole road surface depends upon the condition of the foundation, the subgrade; and the condition of this foundation subgrade depends upon the kind of facilities provided for drainage.

Drainage as applied to a roadway presents two distinct problems: one, the disposal of surface or storm water; and the other, protection from percolation and seepage water. If the first is not properly taken care of, the subgrade under the road will become unstable because of saturation; therefore, the removal of this surface water must be prompt. The second is affected by the water table. When the water table is high, capillary action which draws water up to a considerable height above the free water level will hold the water near the surface and soften the subgrade.

There must be sufficient crown to the improved roadway surface to deliver any storm or surface water over the shoulder to the side ditches quickly but without eroding or washing the surface of earth, gravel, or macadam or cutting and washing the shoulders.

The side ditches must be of sufficient width and depth to carry the water away within a reasonable time after collection to prevent saturation of the subgrade. This requires free flow