Highway Surface Drainage

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INTRODUCTION

The past year, with intense spring rains and large amounts of winter precipitation, has again emphasized to the highway engineers and road supervisors that the fundamental problem of road maintenance and design is drainage. Essentially three drainage problems exist. The first problem is drainage of the roadway and right-of-way. The second problem is concerned with the analysis of the watersheds at culvert and bridge crossing sites. The third problem is the elimination or control of subsurface water.

It is the purpose in this article to briefly discuss the first two problems. The third is to be presented by another member of the panel. Some of the items discussed will be familiar to you. One item, using aerial photographs, may be a new application that might assist you in analyzing runoff of watersheds for new culverts and bridges in your county. In any case, it is one of the purposes of the Purdue Road School to review problems and discuss some of the corrective measures so that we may have county highways suitable for travel under all conditions of weather and not just during dry periods.

DRAINAGE OF THE ROADWAY AND RIGHT-OF-WAY

Drainage of the roadway and right-of-way refers to the removal of all excess surface waters that may penetrate the roadway and decrease the supporting power and stability of the wearing course and subgrade.

Low-cost soil-aggregate mixtures used as wearing course and subgrade will generally give good service under low traffic volumes provided they are *properly crowned* and *contain the correct proportion and type of clay binder* to facilitate drainage.

Crown

A properly constructed and maintained crown on a soil-aggregate road is effective in removing excess water provided that the shoulder or berm is not higher than the edge of the roadway. This last factor is too frequently overlooked, therefore, the edge of roadway acts as a channel and dangerous erosional gullies develop. The crown should slope from the centerline to the side at the rate of from ¼-to ½-inch per foot with high crowns used on grades so that water flows to the side ditch. Water-proofed roads with bituminous surfaces should be crowned from ⅛-to ¼-inch per foot depending upon type of surface with higher types and cement concrete roads receiving less crown. The transverse crown is effective in maintaining good surface drainage provided that it is maintained free of longitudinal ruts. The crown cannot be continuously maintained; therefore, it is important to have a minimum longitudinal grade line of 0.5 per cent to prevent ponding of excess water in ruts and tracks.

Proportion of Binder

The correct proportion of clay binder in the soil aggregate mixture is an extremely important item in sealing and protecting the roadway. The proportion of binder in the soil aggregate mixture will, of course, vary according to type of materials locally available. It may be necessary in some counties, to add small amounts of binder to coarse-textured deposits that are clean and non-plastic. In other counties, it may be necessary to add coarse-textured materials to a soil-aggregate mixture that contains an excessive amount of fine materials. The final soil-aggregate mixture used as a wearing course should contain, as recommended by AASHO, from 8 to 20 per cent by weight of material that will pass through the No. 200 mesh sieve (2). In no case, should the per cent passing the No. 200 sieve exceed two-thirds of the total fraction of soil particles that pass the No. 40 mesh sieve, and the total fraction passing the No. 40 sieve should have a maximum liquid limit of 35 and a plasticity index range of 4 to 9 (2). In all cases, the properly proportioned material should extend the full width of the roadway, and be compacted to high density for a minimum depth of 6 inches. If the material is carried over the full width, the problem of high shoulders may be avoided and traffic may be distributed over greater area instead of being channelized. All these items will assure good surface drainage from the roadway as the proper amount of binder material holds the aggregate mass together during dry weather and helps to seal the surface during wet periods.

Type of Binder

The type of binder is important since it acts as a moisture regulator. It absorbs moisture and expands a small amount so that it seals against the penetration of rainwater. This expansion of the total compacted sample should not exceed 1 per cent during soaking in laboratory tests. A sample that contains excessive amounts of clay or highly expansive clays will swell considerably. This excessive swelling unseats the coarser materials layer by layer causing further penetration of rainwater and subsequent loss of strength. This factor contributes to poor drainage over the entire roadway and maintenance costs become excessively high.

Right-of-way Drainage

Drainage of the right-of-way refers to the construction and maintenance of side slopes and side ditches which remove water away from the roadway. Side slopes should be protected by turf and should range from flat slopes of 4 to 1 on low fills to a steep slope of 2 to 1 on high fills (2). Side slopes on fills can become critical in sag vertical curves where surface drainage of a large segment of the road accumulates and may cause excessive slope erosion. Many of you, I am sure, have experienced the loss of fill material at the ends of bridges or culverts placed at low points in vertical sag curves. In this case, it is important to construct deflector ridges and lined channels to intercept the flow and conduct it down slope before it undermines the bridge approach.

Side ditches in cut sections should be trapezoidal in shape and should be 2 to 4 feet wide. Trapezoidal ditches have greater capacity and can be better protected from erosion by turf than can the V-shaped ditch (5). Ditch side slopes on the roadway side should be 3 to 1 or flatter. On the outside slope, they will vary depending upon type of material in the cut section. If the soil material is unconsolidated, then the side slope should be protected by turf on a maximum slope of 2 to 1. Rock cuts, of course, may be almost vertical if the rock is sound. The depth of the ditch should be sufficient to maintain the continuous water flow at least 12 inches below the roadway surface.

The grade of the ditch should be such that the water velocity during intense storms should be in the range of 3 to 8 feet per second depending upon soil type. Water of high velocity that contains sand, gravel or rock fragments has great erosive power, therefore, shallow grades on trapezoidal ditches are required or check dams may be installed on steep grades to reduce the erosion. V-shaped ditches with steep grades in soil materials containing coarse-textured particles should be avoided or erosion will be severe.

ANALYSIS OF WATERSHEDS

The analysis of watersheds crossed by a highway fill is not an exact science and certain assumptions are made based on judgment. Procedures for analysis of rivers with very large watersheds are fairly well standardized by the use of data collected at stream gaging stations.

There are over 100 stream gaging stations throughout Indiana and records are available. Small watersheds and medium size watersheds are usually analyzed by the use of empirical formulas that either determine waterway opening directly or that are used to determine quantity of water that must be accommodated by a culvert or bridge. Aerial photographs may be used to advantage in the analysis of these small watersheds and considerable time and money may be saved by following the procedures as outlined below.

Talbots Formula

The Talbot formula is in common use because it gives the area of waterway opening directly. It does not take into account variations in the intensity of rainfall, velocity of flow, or other watershed factors, and its indiscriminate use is questioned. The variables in the Talbot formula, $A = C \sqrt[4]{M^3}$, may be evaluated directly on the aerial photographs. The watershed area M in acres may be measured with a planimeter once the drainage divide is marked by stereoscopic study of the aerial photographs. The runoff coefficient C which varies from 1.0 for steep, rocky ground to 0.2 for level terrain not affected by accumulated snow may be estimated directly by use of the aerial photographs (2).

Rational Formula

Watersheds of less than 10,000 acres may easily be evaluated on aerial photographs by use of the rational formula. It is believed that a more logical solution in determining quantity of storm water flow my be obtained by this method. The rational equation, $Q = CIA$, states that if a storm of intensity I (inches/hour $\cong$ cfs/acre) falls upon a watershed of area A (acres) for a duration equal to the time of concentration t_c (minutes) and if a portion of this storm runs off with a coefficient of C then the peak rate of runoff will be Q (cfs).

The area of the watershed (A) in acres may be planimetered on the aerial photographs as outlined under Talbot's Formula.

The coefficient of runoff C is best determined as a weighted coefficient depending upon variations in surface soils, vegetation, slope and land use. The entire watershed area is subdivided into small areas (a) of similar runoff conditions. A coefficient of runoff (c) applicable to the subarea is estimated. Table 1 is a guide that may be used in Indiana to, select the appropriate coefficient if other data are not available. It may be appropriate for small watershed areas to select an average value for C and use this directly in the equation. For large areas, the weighted coefficient is obtained as shown in Table 2.

TABLE 1
RUNOFF COEFFICIENTS FOR URBAN AND RURAL AREAS
(Modified from various sources)

Description of Area	*C*
Residential, flat to rolling, about 30% impervious	0.4-0.6
Residential, rolling to hilly, about 50% impervious	0.6-0.8
Commercial—Industrial, about 70% impervious	0.6-0.9
Cultivated, flat, slopes less than 5%	0.2-0.4
Cultivated, rolling, slopes less than 10%	0.4-0.6
Cultivated, hilly, slopes greater than 10%	0.6-0.8
Pasture, rolling, slopes less than 10%	0.1-0.4
Pasture, hilly, slopes greater than 10%	0.3-0.6
Timber, rolling, slopes less than 10%	0.2-0.4
Timber, hilly, slopes greater than 10%	0.3-0.5
Bare earth and rock, slopes less than 30%	0.4-0.8
Bare earth and rock, slopes greater than 30%	0.7-0.9
Upland farms on flat ridge tops	0.3-0.5

TABLE 2
EXAMPLE FOR A 1000-ACRE WATERSHED

Description	*c*	*a*	*ca*
Residential rolling	0.7	200	140
Cultivated rolling	0.4	500	200
Pasture rolling	0.2	100	20
Timber, hilly	0.4	200	80
		a 1000	ca 440

$$\text{Weighted C} = \frac{ca}{a} = \frac{440}{1000} = 0.44$$

The intensity of rainfall I is dependent upon the time of concentration (t_c). The empirical expression $t_c = 60 \left[\frac{11.9L^3}{H}\right]^{.0385}$ for determining time of concentration within a channel, or a similar expression that was developed for the region of study may be used (2). A method of determining time of concentration for overland flow until a channel is reached is presented in Reference 3. In the equation above t_c is determined in minutes, L is the developed length of the longest channel in the watershed as measured on the photographs in miles, and H is the fall of the channel expressed in feet. H may be obtained from topographic maps such as the 7½ minute USGS

Quadrangle sheets, the 1:250,000 series for Indiana by USGS, or H may be obtained by field surveys or by anneroid barometer surveys. Frequently it is necessary to consider both overland flow and channel flow in determining time of concentration and two separate calculations are made.

Once the time of concentration (t_c) is determined, then it is assumed that the storm duration is equal to the time of concentration for maximum flow. The intensity of rainfall may be computed by use of the equation in the form $I = \frac{k}{t_c + m}$ if the storm duration is less than two hours or $I = \frac{k}{(t_c)h}$ if the duration is greater than two hours. These expressions and values of the constants for various regions of the United States may be found in A. F. Meyer's *Elements of Hydrology* and in M. W. Bernard's article in *Transactions* ASCE (4, page 196 and 1, page 600). The intensity formulas applicable to the northwest part of the state of Indiana are shown in Table 3. The constant K for durations greater than 2 hours may be increased or decreased from 5 to 20 points in the state of Indiana in the southeastern direction, and the designer must select the constants applicable to the particular area.

The determination of the quantity of water (Q) that must be handled by the culvert or bridge may then be computed by the rational formula since C, I and A are known for the particular watershed under investigation. The culvert design or bridge waterway opening may then be determined by the principles of hydraulics.

TABLE 3

RAINFALL INTENSITY FORMULAS

Northwestern Indiana

Frequency	*Durations less than 2 Hours*	*Durations Greater than 2 Hours*
5 years	$I = \frac{122}{t_c+18}$	$I = \frac{35}{t_c^{0.75}}$
10 years	$I = \frac{150}{t_c+19.5}$	$I = \frac{40}{t_c^{0.76}}$
25 years	$I = \frac{181}{t_c+21}$	$I = \frac{50}{t_c^{0.76}}$
50 years	$I = \frac{216}{t_c+23}$	$I = \frac{65}{t_c^{0.77}}$
100 years	$I = \frac{256}{t_c+25}$	$I = \frac{80}{t_c^{0.78}}$

Each county is now engaged in a culvert and bridge reconstruction program. It is believed that the study of individual watersheds by the rational method as outlined above will make for more economical designs best suited for particular sites within each county.

REFERENCES

1. Bernard, M. M. "Formulas for Rainfall Intensities of Long Duration," *Transactions* ASCE, Vol. 96, pp. 592-624, 1932.
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3. Kerby, W. S. "Time of Concentration for Overland Flow," *Civil Engineering,* March, 1959, page 60.
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5. *Handbook of Drainage and Construction Products,* Armco International Corporation, 1955.