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 in the ditches, but without such velocity as will erode and wash away the shoulders of the roadway or the back slopes of the ditch.

The cross drainage, culverts and bridges, under the roadway, must be of sufficient cross-sectional area of opening to deliver all water safely without danger of backing and ponding, thereby causing the flow to be under a head—a source of erosion, undercutting, and washouts. Ample area is well worth the slight added expense involved in providing the few square feet of additional opening.

Survey Data

At the time when the field surveys are being made, the survey party should collect complete and full information about all culvert and bridge openings. A few of the important items of information needed by the design office are:

Measurements of the existing bridge or culvert.
Notes on the next bridge, both upstream and downstream.
Size and area of the waterway openings.
Length of the culvert.
Length and number of spans in the bridge.
Estimate of drainage area served.
Notes on indications of high water.
Elevation of present road above stream.
Elevation of present flow grades.
Stream profile for from 100 to 500 feet each way, depending upon the size of the stream.
Subsoil and surface soil report.
Soundings of depth sufficient to insure good foundations.

Lack of complete information concerning the requirements of drainage openings has been the base reason for many errors in design of these facilities. They must be designed right at first, for later on, if unsuited to the location, they can only be changed at very high expense in time, money, and interference with traffic.

The area which delivers water to the culvert or bridge should be given critical study. How extensive is the area? What are its slopes? Is the land level, rolling, hilly? Is the soil sand, loam, clay, gravel, or rock? Are the levels and slopes cultivated; in meadow; or in brush and timber? All these factors affect the quantity of water which must be handled, the velocity of flow, the time of concentration, and thus the size of the opening required.

The water to be taken care of comes from precipitation in form of rain, snow, sleet, or hail, the greatest portion being supplied by rain. Rainfall is measured in inches of depth over the drainage area. Rainfall statistics for any given locality may be had from the United States Weather Bureau.

The drainage opening must be sufficient in size to pass the run-off water as fast as it accumulates; it is necessary therefore to know the intensity of rainfall, or the rate of precipitation. This is given in the records in inches per hour. Storms vary in intensity. Those of low rate and considerable duration outnumber those of short, high intensity. For country studies it is sufficient to let the storms of 10- to 25-year occurrence govern the design.

Not all the rainfall gets into the streams and rivers. A certain part is lost through seepage, percolation, and evaporation, and in plant growth. The factor of run-off varies with the slope and the soil, whether the ground is under cultivation, or is woodland or forest. For good results the run-off factor may be taken as: 1 for steep and rocky ground with abrupt slopes; 2/3 for hilly ground of moderate slopes; ½ for uneven valleys, wide as compared to length; 1/3 for rolling agricultural land; 1/5 for level lands not affected by severe floods.

The rainfall must be taken from the roadway, the ditches, and the drainage area, and passed through the culvert or bridge at a safe velocity to minimize erosion and wash. The ditches along the roadway must carry the water from the roadway and a certain amount from the adjacent fields. The quantity of water to be carried is estimated from the rainfall, the run-off factor, the area, and the time of concentration. This is reduced to cubic feet per second.

Let

A = drainage area,
C = run-off factor,
i = expectancy of rainfall in inches,
t = time of concentration,
R = run-off in inches per hour,
D = discharge in cubic feet per second.

Then

$$i = \frac{120}{t-15}$$

$$R = Ci$$

$D = RA$ (in terms of cubic feet per second).

The quantity of water that the ditch will carry is

$$D = aV$$

where

D = quantity of water in cubic feet second,
a = area in square feet of cross-section of flowing water,
V = average velocity of flow in feet per second.

V is unknown but can be determined from

$$V = c\sqrt{rs}$$

c is a constant which takes into consideration all the retarding factors to flow which exist in the channel or ditch.

r is the hydraulic radius, which is the cross-sectional area in square feet of the flowing water divided by the wetted perimeter of the channel.

s is the slope ratio or grade of the channel.

c for ordinary channels will vary from 55 to 127, but may be determined from Kutters' equation

$$c = \frac{41.6 + \frac{1.811}{n} + \frac{0.00281}{s}}{1 + \left(41.6 + \frac{0.00281}{s}\right)\frac{n}{\sqrt{r}}}$$

The value given n for ordinary ditches is 0.02 to 0.025.

Location of Culvert

Three methods are in general use for determining the size of a culvert opening.

a. Inspection of the old structures on the site, also the structures upstream and downstream.

b. Use of some empirical formula which will give an approximation close to the exact area.

c. Use of some of the more exact formulae to determine the amount of water which reaches the culvert, and then determination of the size of opening required to pass this water.

The first method is practical. The old structures standing over the stream have passed the stream waters for years. However, it may be that these structures are too large. Investigation of highwater records will show whether the opening of the old structure is too large or too small. If high water records are doubtful, a sufficient allowance as a factor of safety should be added.

Empirical formulae are in extensive use. These are based on observations covering a large number of culverts and bridges which have proved satisfactory in carrying the run-off from watersheds and basins having various general characteristics. These formulas are admitted to give only approximate results, but this is well known and understood by engineers, and it is also known that conditions are such that computations for culvert sizes do not ordinarily or readily fit into mathematical precision. Rainfall, slope, size, shape of basin, vegetation, condition of soil, and many other variables form a great variety of combinations—an infinite number—and these do not lend themselves to exact figures. Therefore an empirical formula, having an ample factor of safety under general conditions, is the simplest and most practical to use for determination of area.

Talbot's equation, being simple and easy of application, is in very general use for the determination of culvert and small bridge openings.

$$A = c\sqrt[4]{D}$$

A = area of required opening in square feet.
c = a constant depending upon the nature of the drainage basin.
D = area of the drainage basin in acres.

The values arrived at by the use of this equation are ample for all ordinary locations. Special locations or unusual conditions should be given a very careful study.

The culvert if designed for the maximum rainfall as shown by the records as having occurred once in 10 to 25 years, will seldom run full, and will have a large enough opening to care for all ordinary rainfalls with an ample factor of safety. An opening high and narrow is not as efficient in removing water as one of equal area but lower in height and wider.

The length of culvert needed will depend upon the shoulder width of the roadway, the height of fill, the side slopes on the embankment, and sometimes the skew angle of the crossing. Every culvert should be of sufficient length to prevent danger of filling with material washed from the bank or out from the ditches. A short culvert is uneconomical, has low efficiency and high maintenance. The length should be determined from the cross-section sketch at the location and the profile of the creek bed. For a square crossing, the length of the culvert may be found by adding to the shoulder width of the roadway, two times the slope ratio of the bank times the fill depth at the center line.

Location of Culvert

The proper location of the culvert crossing is a very important factor, for this affects the efficiency, cost of maintenance, and length of service and may contain the possibility of erosion and washout. Each culvert is a study by itself.

The culvert or small bridge is a restricted channel, substituting for the open stream or creek where the watercourse passes under the roadway. Not every stream is of stable character. Stream channels change, shift from side to side of the valley. Scour and erosion occur, digging in at this place, filling up at some other place. A stable stream under existing conditions may, because of change of conditions, become unstable. The culvert or bridge when located becomes a fixed point in the streamway. Good judgment and careful thought should be applied to all locations, for when once installed, this kind of facility cannot be moved or changed without much expense and irritating interference with the public.

A stream crooked or course-changing should be relocated and straightened. The cost of channel change may be offset by savings in cost of construction of the culvert or bridge.

Certainly the added insurance against washout is well worth study and some added preliminary expense for construction.

If the stream line is satisfactory, make the axis of the culvert coincide with that of the stream. The line of entrance for the water should be as direct as possible, and likewise the exit. If there is an abrupt change in direction at either end of the culvert, the flow is retarded and a larger opening is required, and there is added hazard of erosion and wash. If the stream crosses the road at an angle, the construction is to skew the culvert with the road rather than force the stream to cross at right angles to the road line.

Use all reasonable precautions at the culvert ends to prevent the stream from changing its course. A change of course may block the culvert, back up the water, cause the roadway to wash out. If there is any evidence of such tendency, use plenty of riprap at the danger spots. Prevention is better than washouts and reconstruction.

Do not set the culvert too low. All new work exposes fresh earth which erodes and washes easily, and if the culvert is low, sedimentation takes place, whereby the effective area is reduced, possibly to the danger limit.

Give the culvert the same general slope as the stream bed. If the stream carries silt, there is danger that if the slope is made flat to prevent erosion, sedimentation will take place. Placing the culvert on a steeper slope to increase the velocity and thus use a smaller opening may result in scour at the outlet end. The slope of the stream bed is the best guide. If the slope must be steep, then protect the outlet with paving or riprap.

Small Bridges

The small bridge is a problem on all roads. It needs careful preliminary study, thoughtful choice as to type of design and kind of construction. Sometimes temporary expedients are tried; safety is sacrificed by restricting the roadway in order to save on construction costs. The area of waterway should be ample to carry the expected flow of the storms of 10- to 25-year occurrence. Foundations should be carefully investigated, for unless they are of satisfactory load-bearing materials, piling must be used. The bridge should be placed to get the free flow of the stream. If evidence shows that scour and erosion are to be expected, safety may be built into the bridge by using piling under the footings and riprap protection extending from the wing walls on the upstream and on the downstream sides.

Scour occurs in different soils at different velocities: in sand, when the velocity is 2 to 3 feet per second; in loam, when the velocity is 2 to 3½ feet per second; in gravel, if firm, when the velocity is 5 to 6 feet per second.

Good hand-riprap of stones more than one-half cubic foot in volume will not be moved unless the velocity of the water exceeds 12 feet per second.

The bridge should be designed to fit the highway alignment, grade, and location. Make a real effort to adjust these so that the finished job may be pleasing to the eyes, not complicated, and not needlessly expensive.

Structures for small openings should be selected for efficiency, economy, and practicability from the following types: pipe culverts, concrete boxes, slab-top culverts, flat slab and T-beam bridges, and arch culverts. The minimum size of pipe culverts should be not less than 12 inches in diameter. Large size pipes may be used but concrete boxes usually are more economical for areas over 6 square feet. Slab-top culverts may be used in flat country where there is probability of future deepening of drainage ditches. For spans from 10 to 20 feet, flat slab bridges are suitable; T-beam bridges are better for spans of 20 to 30 feet. If either of the last-mentioned openings is required under a fill of considerable height, an arch top or box culvert of adequate size should be used.

If necessary to obtain satisfactory waterway area, channel improvements should be made at the bridge, both under and adjacent to the site. Many times the flow will be improved by relocating the stream either above or below the bridge. Where such a channel change is considered, the controlling factor should be the question whether the benefit accruing to the highway and the bridge will justify the expenditure of the sum of money required for the improvement. At times the channel-change material may be useful in building roadway fill. Keep in mind the riparian rights of the property owners when making the study and investigation, for their rights must be protected.

Summing up, we agree that drainage is of such importance that it needs careful and thoughtful consideration. More drainage openings are often required than the number placed under the roadway. The acres in the drainage basin, the amount of rainfall over this area, the run-off to be expected at the waterway opening, all influence the square feet of opening required to pass the water at safe velocity. The area of the waterway opening should be made oversize within reason to provide the factor of safety desired against the unexpected heavy storm. Additional square feet of area opening are far more economical and cheaper than washouts and reconstruction of the roadway and the culvert or bridge. Plan the structure so that it will fit the locality, the road alignment and grade, with least complicated design and construction, and will satisfy the condition of being pleasing to the eye.