Highway Drainage

Proper drainage is a very important consideration in design of a highway. Inadequate drainage facilities can lead to premature deterioration of the highway and the development of adverse safety conditions such as hydroplaning. It is common, therefore, for a sizable portion of highway construction budgets to be devoted to drainage facilities. In essence, the general function of a highway drainage system is to remove rainwater from the road and water from the highway right-of-way. The drainage system should provide for the drainage conditions described in Arts. 2 and 3.

1- Storm Frequency and Runoff

Storm frequency refers to the chance that a given intensity of rainfall will occur within a specific span of years. It is determined from historical data that indicate that a particular intensity of rainfall can be expected once in $N$ years. A drainage system designed for such an intensity is intended to be capable of withstanding an $N$-year storm, runoff, or flood. A 25-year storm, for example, represents a 1 in 25 probability that the drainage system will have to accommodate such an intensity. This does not mean that every 25 years a certain storm of this magnitude will occur. It is possible that such a storm will not occur at all during any 25-year period. It is also possible, however, that two or more such storms will take place in a single year. The odds of this happening, though, are relatively small. For highways, cross drains (small culverts) passed under major highways to carry the flow from defined watercourses are typically designed to accommodate a 25-year storm. Larger culverts and bridges on major highways are designed with capacity for 100-year storms. For nonmajor highways, the storm used for design can range from a 10- to 50-year storm, depending on the highway size and traffic volume expected.

1.1- Runoff Determination

The amount of runoff to be used for design of surface drainage can be determined through physical stream-flow measurements or through the use of empirical formulas. A common approach is to utilize the rational method (also known as the Lloyd-Davies method in the United Kingdom). While this approach gives reasonable answers in most urban areas, care must be taken when applying the rational method in rural areas. Runoff for rural and large watershed areas is much more difficult to estimate accurately than the runoff in urban environments. Typically, for determination of runoff, a large watershed is divided into several
smaller watershed areas, from which runoff flows to various inlets or waterways. In general, conservative design values of runoff can be determined for drainage areas of 100 acres or less. Some designers, however, have used 200-acre and even 500-acre maximum values.

2- Surface Drainage
Provision must be made for removal of water, from rain or melting snow, or both, that falls directly on a road or comes from the adjacent terrain. The road should be adequately sloped to drain the water away from the travel lanes and shoulders and then directed to drainage channels in the system, such as natural earth swales, concrete gutters, and ditches, for discharge to an adjacent body of water. The channels should be located and shaped to minimize the potential for traffic hazards and accommodate the anticipated storm-water flows. Drainage inlets should be provided as needed to prevent ponding and limit the spread of water into traffic lanes.

2.1- Surface Drainage Methods
For rural highways on embankments, runoff from the roadway should be allowed to flow evenly over the side slopes and then spread over the adjacent terrain. This method, however, can sometimes adversely impact surrounding land, such as farms. In such instances the drainage should be collected, for example, in longitudinal ditches and then conveyed to a nearby watercourse. When a highway is located in a cut, runoff may be collected in shallow side ditches. These typically have a trapezoidal, triangular, or rounded cross section and should be deep enough to drain the pavement subbase and convey the design-storm flow to a discharge point. Care should be taken to design the ditches so that the toe of adjoining sloping fill does not suffer excessive erosion. For larger water flows than the capacity of a shallow ditch, paved gutters or drainpipes with larger capacities will have to be used. In urban environments and built-up areas, use of roadside drainage channels may be severely limited by surrounding land uses. In most instances, the cost of acquiring the necessary right-of-way to implement such drainage facilities is prohibitive. For highways on embankments, a curb or an earth berm may be constructed along the outer edge of the roadway to intercept runoff and divert it to inlets placed at regular intervals. The inlets, in turn, should be connected to storm sewers that convey the water to points of disposal. In an urban area, it may be necessary to construct storm sewers of considerable length to reach the nearest body of water for discharge of the runoff.
2.2- Inlets

These are parts of a drainage system that receive runoff at grade and permit the water to flow downward into underground storm drains. Inlets should be capable of passing design floods without clogging with debris. The entrance to inlets should be protected with a grating set flush with the surface of gutters or medians, so as not to be a hazard to vehicles. There are several types of inlets. A drop inlet is a box-type structure that is located in pipe segments of a storm-water collection system and into which storm water enters from the top. Most municipal agencies maintain design and construction standards for a wide variety of inlets, manholes, and other similar structures, but some large structures may require site-specific design. A curb inlet consists of a vertical opening in a curb through which gutter flow passes. A gutter inlet is a horizontal opening in the gutter that is protected by a single grate or multiple grates through which the gutter flow passes. A combination inlet consists of both gutter and curb inlets with the gutter inlet placed in front of the curb inlet. Inlet spacing depends on the quantity of water to be intercepted, shape of ditch or gutter conveying the water, and hydraulic capacity of the inlet.

2.3- Storm Sewers

These are underground pipes that receive the runoff from a roadside inlet for conveyance and discharge into a body of water away from the road. Storm sewers are often sized for anticipated runoff and for pipe capacity determined from the Manning formula. In general, changes in sewer direction are made at inlets, catch basins, or manholes. The manholes should provide maintenance access to sewers at about every 500 ft. A storm sewer system for a new highway should be connected to an existing drainage system, such as a stream or existing storm sewer system. If a storm sewer is to connect to a stream, the downstream conditions should be investigated to ensure that the waterway is adequate and that the new system will not have an adverse environmental impact. If the environmental impact is not acceptable, it will be necessary to study possible improvements to downstream outlets to accommodate the additional flow or to make the drainage scheme acceptable to local officials in some other fashion.

2.4- Open Channels

As indicated in Art. 2.1, side ditches may be used to collect runoff from a highway located in a cut. The ditches may be trapezoidal or V-shaped. The trapezoidal ditch has greater
capacity for a given depth. Most roadway cross sections, however, include some form of V-shaped channel as part of their cross-sectional geometry. In most instances, it is not economical to vary the size of these channels. As a result, this type of channel generally has capacity to spare, since a normal depth must be maintained to drain the pavement subbase courses. When steep grades are present, the possibility of ditch erosion becomes a serious consideration. Erosion can be limited by lining the channel with sod, stone, bituminous or concrete paving, or by providing small check dams at intervals that depend on velocity, type of soil, and depth of flows. Linings for roadside channels are typically classified as either rigid or flexible. Paved and concrete linings are examples of rigid linings. Rock (riprap) and grass linings are examples of flexible linings. While rigid linings are better at limiting erosion, they often permit higher water velocities since they are smoother than flexible linings. Roadside channels are often sized for anticipated runoff and for open-channel flow computed from the Manning equation. This equation includes a roughness coefficient $n$ that may range from as low as 0.02 for concrete to 0.10 for thick grass. Flow down gentle slopes is likely to be subcritical whereas flow down steep slopes may be supercritical. When the water depth is greater than the critical depth, subcritical flow occurs. Conversely, when the depth of water is less than the critical depth, supercritical flow occurs. The abrupt transition from subcritical to supercritical flow takes the form of a hydraulic jump. Open channels should be designed to avoid supercritical flow. The reason for this is that water moving through a channel at high speeds can generate waves that travel downstream and cause water to overtop the sides of the channel and scour the downstream outlet. To limit the effects of scour at the outlet, energy dissipators may be incorporated in the channel. An energy dissipator may be a drop structure that alters the slope of the channel from steep to gentle. Alternatively, roughness elements, such as blocks and sills, can be placed in the channel to increase resistance to flow and decrease the probability of hydraulic jump’s occurring.

2.5- Culverts

A culvert is a closed conduit for passage of runoff from one open channel to another. One example is a corrugated metal pipe under a roadway. Figure (1) shows various types of culvert cross sections and indicates material types used in highway design. For small culverts, stock sizes of corrugated metal pipe may be used. For larger flows, however, a concrete box or multiple pipes may be needed. If the culvert foundation is not susceptible to erosion, a bridge
may be constructed over the waterway (bridge culvert). The section of a culvert passing under a highway should be capable of withstanding the loads induced by traffic passing over the culvert. Since corrugated metal pipes are flexible, they are assisted by surrounding soil in carrying gravity loads. Reinforced concrete culverts, however, have to support gravity loads without such assistance. Empirical methods often are used for selecting and specifying culverts. With the use of data from previous experience, designers generally select small-sized culverts from standards based on the characteristics of the project to be constructed. Larger concrete arch and box-type structures, however, are designed for the specific service loads. Culverts are generally installed in an existing channel bed since this will result in the least amount of work in modifying existing drainage conditions. To avoid extremely long culvert lengths, however, it may be necessary to relocate an existing channel.

Fig. (1) Culvert cross sections: (a) circular pipe, usually concrete, corrugated metal, vitrified clay, or cast iron; (b) elliptical pipe, generally reinforced concrete or corrugated metal; (c) precast concrete pipe arch; (d) corrugated metal or reinforced concrete arch; (e) reinforced concrete box culvert; (f) reinforced concrete bridge culvert.

3- Subsurface Drainage

Water in underlying soil strata of a highway can move upward through capillary action and water can permeate downward to the underlying soil strata through cracks and joints in the pavement. In either case, the water can cause deterioration of the roadbed and pavement. To prevent this, subsurface drainage is used to remove water from the highway subgrade and intercept underground water before it flows to the subgrade. Although design of subsurface
drainage systems depends on the specific geometry, topography, and subsurface conditions of the site to be drained, subsurface drainage facilities should be considered an integral component of the entire highway drainage system rather than treated as a separate component. Failure to implement subsurface facilities that meet drainage requirements can lead to failure of major segments of the highway and to slope instability. Figures (2) to Fig. (4) illustrate some commonly used subgrade drainage methods. Figure (2) shows an intercepting drain installed to cut off an underground flow of water to prevent it from seeping into the subgrade of a road. The top of the trench is sealed to prevent silting. In Fig. (3), drains are shown employed on both sides of a road to remove surface water that may be trapped when a pervious base is laid over a relatively impervious subgrade. When this detail is used, the longitudinal base drains should be outletted at convenient points, which may be 100 ft apart or more. On steep slopes, lateral drains may be added under the pavement. Figure (4) shows a typical bedding and backfill detail for a pipe underdrain. It is constructed by digging a trench to a specified depth, placing a pipe in the trench, and then backfilling the trench with a porous, granular material. The pipes are generally fabricated of perforated corrugated metal pipe, vitrified clay, or porous concrete. Sizing of pipes is typically based on previous experience, but large projects may require site-specific design.

Fig. (2) Drain intercepts source of supply of harmful capillary and free water under a road. Top of trench is sealed to prevent silting. ("Handbook of Drainage and Construction Products," Metal Products Division, Armco Steel Corp.)
Fig. (3) Drains remove surface water that may be trapped when a pervious base is laid over a relatively impervious subgrade. On steep slopes, lateral may be added under the pavement. Longitudinal base drains should be outletted at convenient points, which may be 100 ft or more apart. ("Handbook of Drainage and Construction Products," Metal Products Division, Armco Steel Corp.)

Fig. (4) Underdrain detail.