CHAPTER 7

DRAINAGE OF PAVEMENTS

7-1. Drainage control

Adequate drainage of surface and ground water is one of the most important considerations in the design, construction, and maintenance of roads, railroads, airfields, parking areas, and cantonments. Disposal of surface runoff and removal of excess ground water are vital to the stability of serviceability of foundations and pavements. The entire serviceability of a pavement depends on the adequacy of the drainage system in that a washout of a single culvert may close a facility to traffic at a vital time. Properly designed and constructed drainage systems are equally important to the functioning of cantonment and training areas. Water is directly or partly responsible for most pavement failures and deterioration. Proper drainage is a fundamental of preventive maintenance. All pavement failures should be investigated for deficient drainage, which will be corrected, if possible, to prevent its recurrence.

a. Ponding or delayed runoff of surface water. Although sometimes incorporated as a deliberate feature of economical drainage design, this problem may cause seepage unless the soil involved is impervious or protected by a waterproofed layer. Water will not be allowed to pond on pavements because it interferes with effective and convenient use of traveled areas and introduces hazards such as skidding or loss of steering and braking control. Water standing on a pavement surface can also seep into the base course unless the surface is tightly sealed.

b. Water saturation and pavement foundation weakening. Bearing capacity of subgrades and bases varies with moisture content. Load-carrying capacity of subgrade is highest at optimum moisture content (about 10 percent for sandy soils and from 12 percent to about 25 percent for silt and clay soils). Drying of some materials and saturation of others lower stability. Plastic soils with large silt and clay content shrink when dried and swell upon wetting. Drying of foundation soils is rare because the pavement structure deters evaporation. Moisture control of subgrades and bases is therefore largely a problem of drainage. Excess water comes from percolation through and along the edges of the pavement, from underground seepage and capillary rise, and in areas where the water table is naturally high.

7-2. Types of drainage systems

All drainage systems fall into two classifications: surface or subsurface, depending on whether the water is above or below the surface of the ground when it is first intercepted or collected. Where both types of systems are required for effective maintenance and protection of pavements, it is generally good practice for each system to function independently.

a. Subsurface drainage. Subsurface drainage will be required in areas where ground water is encountered near the base of foundations and pavements. The ground-water table is relatively close to the surface in swampy and coastal areas and in certain inland areas. Surface water can also seep down through open or unsealed surfaces and move laterally along the top of impervious strata to form a subsurface lake or perched water table. Subsurface drainage will be provided to intercept, collect, and remove any flow of ground water into the base course or subgrade; to lower high-water tables; to drain water pockets or perched water tables; or any combination of these purposes. A subsurface drainage system comprises facilities to collect and dispose of water that occurs below the surface of the ground. Subsurface drainage facilities include open-jointed, perforated, or porous collector pipes; conduits; observation risers; cleanouts; filters; blind drains; outlet structures; and appurtenant works as required (fig 7-1).

(1) *Collector pipes*. These pipes are buried in porous material and they conduct the water away. The pipes are usually slotted or in some way porous. If slotting or holes in subdrain pipe cannot be properly sized to prevent soil intrusion, a filter blanket or filter fabric will be needed. The size and type of pipe required is based upon the estimated drainage requirements.

(2) *Conduits*. Conduits usually connect with several collector pipes to carry the water away. These conduits are large enough to carry the flow and to accommodate some silting.

(3) *French drains.* a French drain or French conduit is made of coarse gravel or crushed rock. It can be inexpensive and effective where the amount of water is small. This drain must be protected by a filter or a filter fabric to prevent clogging.

b. Surface drainage. Surface drainage provides for the interception, collection, and removal of surface runoff (fig 7-2). Typical examples include shoulders, swales, gutters, ditches, channels, terraces, and dikes; underground pipe and conduits, inlets, manholes, and junction structures; culverts and bridges; drop structures, chutes, energy dissipators, and erosion control structures; detention ponds, infiltration or leaching basins, pumping stations.

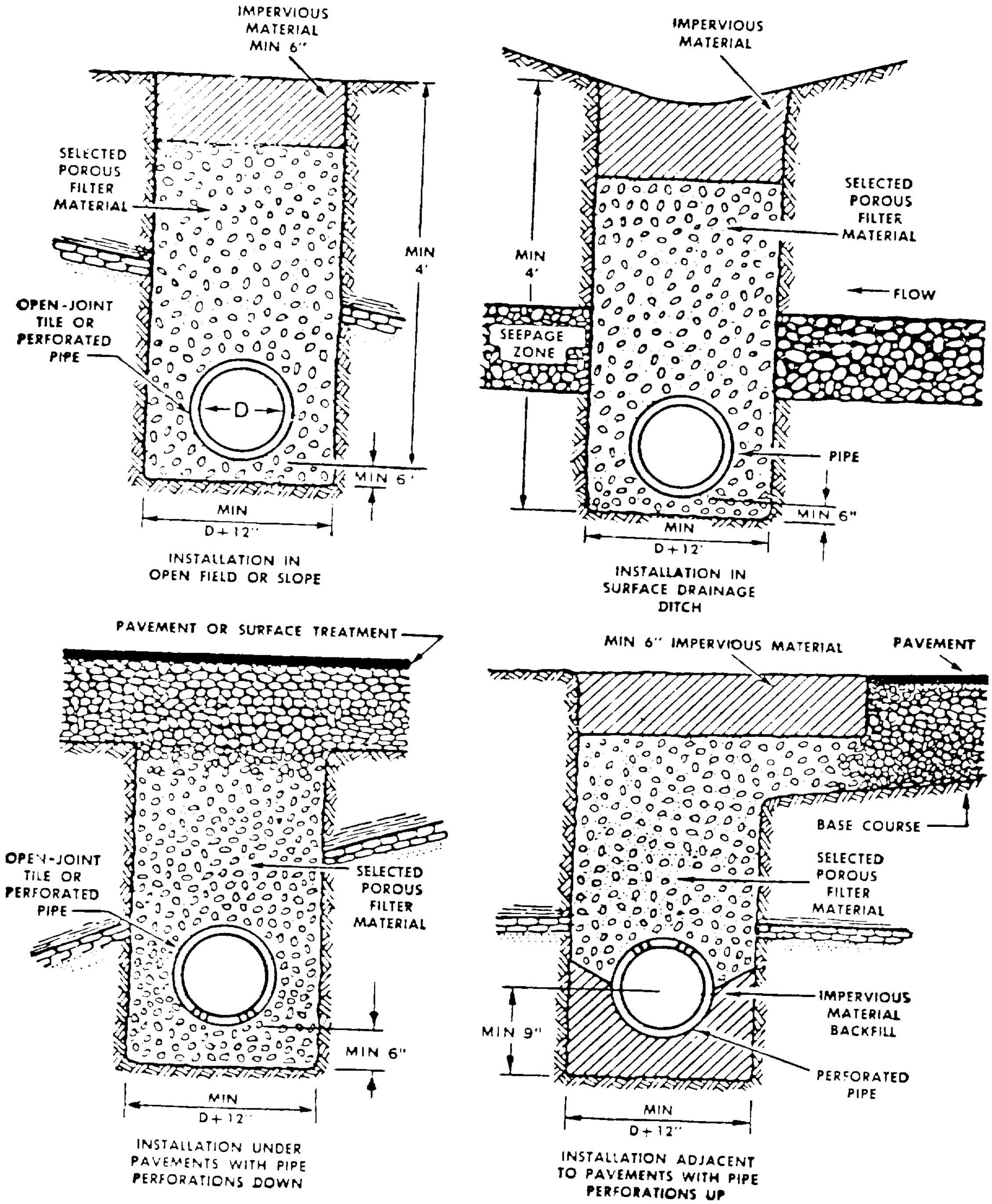

Figure 7-1. Typical subdrain installation.

Properly designed and maintained surface drainage systems may reduce the need for special facilities for control and disposal of ground water.

(1) *Shoulders*. Shoulders receive the water from the roadway and carry it away from the drainage area. Chapter 6 contains more information pertaining to shoulders.

(2) *Ditches and channels*. These are used to carry surface water from drainage areas. The ditches and channels will be of adequate size and type to handle the expected flow conditions. Side inflow will be introduced into a channel at necessary locations rather than randomly along the sides. Terraces and/or levees may be used to prevent side inflow from entering the channel except at desired locations where side channels or pipes are provided to discharge the side flow into the main outfall channel. Flumes will be installed on the surface of steep slopes to carry accumulations of surface water to open ditches or drainage channels (fig 7-3).

They are used to discharge water collected by gutters, berms, or dikes. Flumes will be constructed of various materials including sod, corrugated sheet metal, wood, stone, bituminous hot mix, and concrete.

(3) *Culverts and storm drains*. Culverts and storm drain inlets receive the water from the shoulders, ditches, and channels. Short culverts under sidewalks may be as small as 6 inches in diameter if they can be kept comparatively free of debris or ice. Pipe diameters or pipe-arch rises will not be less than 12 inches beneath vehicular pavements. The use of larger sizes in lieu of inlet grates or trash racks is recommended for areas subject to windblown debris or for sections greater than 30 feet.

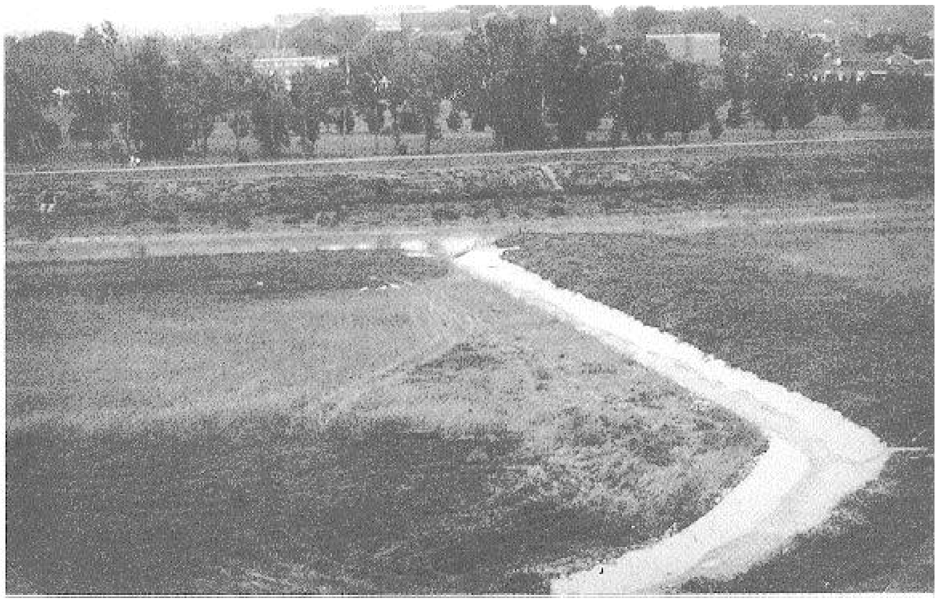

Figure 7-2. Concrete open drainage ditch.

Figure 7-3. Concrete flume for discharging water into drainage channel.

7-3. Types and causes of drainage related distress

Properly constructed and maintained drainage structures can provide satisfactory performance with only minor periodic maintenance. Faulty installation combined with infrequent or improper maintenance will lead to extensive repairs or replacement of pavement structure.

a. Erosion. Erosion is the direct result of flowing water, and in any instances it cannot be completely prevented but only controlled. Erosion at culvert outlets is one of the most prevalent problems concerning surface drainage facilities. Two types of channel instability can develop downstream from a culvert and/or storm-drain outlet, i.e., either gully scour or a localized erosion referred to as a scour hole. Distinction between the two conditions and prediction of the type anticipated for a given field condition can be made. A comparison of the original channel is illustrated in figure 7-4. Erosion behind and around the ends of headwalls and endwalls is also a problem. This is particularly evident at multiculvert installations and at single culverts located beneath the low point of roads and streets. Curb inlets and paved chutes could possibly convey flow over a recessed portion in the top and center of such walls, alleviating this erosion and maintenance problem.

(1) *Gully scour*: Gully scour is often a problem at the discharge end of culverts. Gully scour usually begins at a control point downstream where the channel is stable and progresses upstream. If sufficient difference in elevation exists between the out 40 let and the section of stable channel, the outlet structure will be completely undermined. One of the chief causes of gully scour is the practice of locating outlets at a high elevation relative to a stable downstream grade to reduce quantities of pipe and excavation. The extent of the erosion will depend upon the location of the stable channel section relative to the outlet discharge with respect to both the vertical and horizontal downstream directions. Gully erosion may be prevented or controlled by locating the storm-drain outlets and energy dissipators where the slope of the downstream channel or drainage basin is naturally mild and remains stable under the anticipated velocities; otherwise, the velocity of water will be directed by ditch checks (fig 7-5), drop structures, and/or other means to a point where a naturally stable slope and cross section exist. Outlets and energy dissipators will not be located within channels or drainage basins experiencing disposition. They will be located adjacent to the perimeter and provided with an outlet channel that is skewed rather than perpendicular to the main channel or basin.

(2) *Scour hole*. A scour hole or localized erosion will be experienced downstream of an outlet even if the downstream channel is stable. The severity of damage to be anticipated depends upon the existing conditions at the culvert outlet. In some instances, the extend of the scour hole may be insufficient to produce either instability of the embankment or structural damage to the outlet. However, in many cases, flow conditions produce scour to the extent that embankment erosion as well as structural damage of the apron, endwall, and culvert is evident.

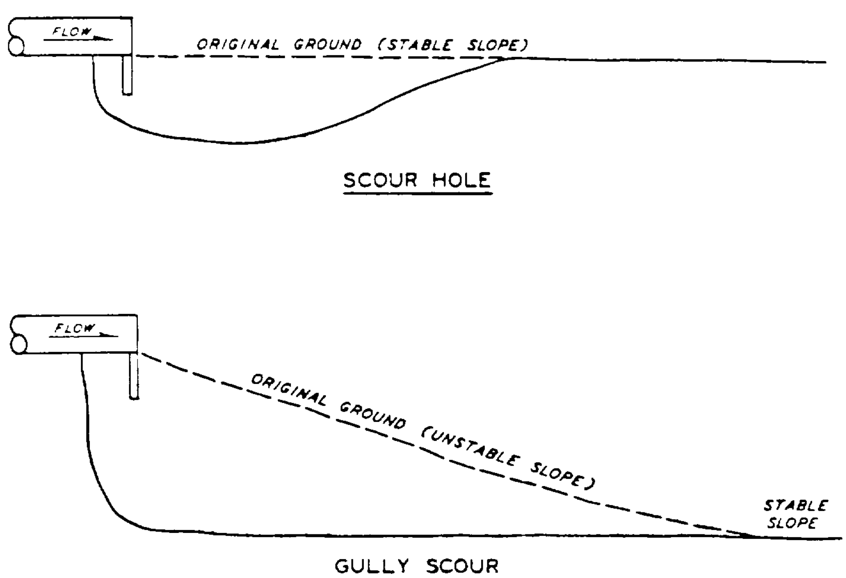

Figure 7-4. Types of scour at culvert outlets.

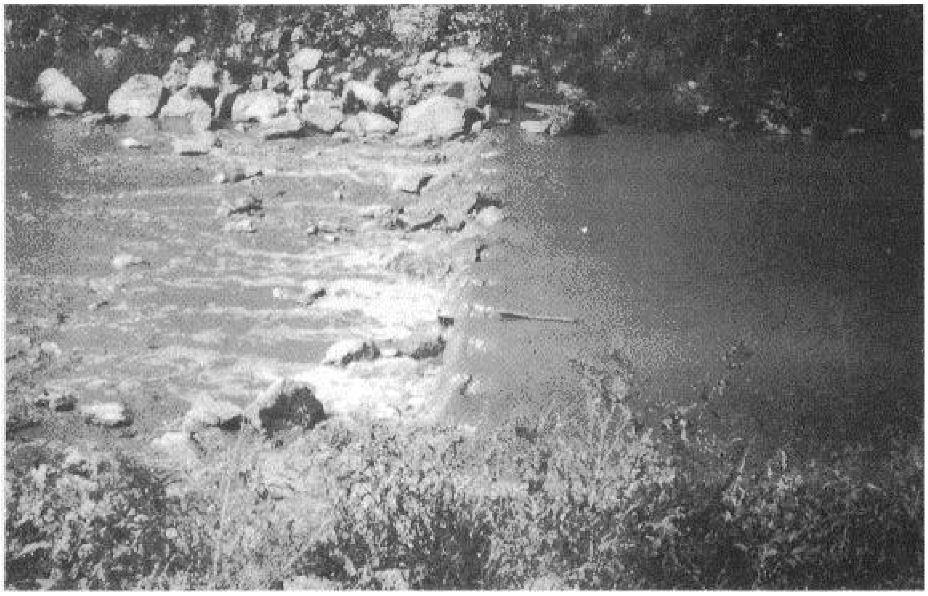

Figure 7-5. Ditch check.

A scour hole will reach a maximum size and then stabilize itself.

b. Infiltration of soil. Infiltration of soil is a serious problem, particularly along pipes in relatively steep slopes and those having a broken-back multisloped barrel. Watertight jointing is especially needed in culverts and storm drains under these conditions in order to prevent infiltration and/or leakage and piping. These normally result in the progressive erosion of the embankments and loss of downstream energy dissipators and pipe sections. Cohesionless soils, particularly fine sands and silts, are most susceptible to piping.

c. Flow obstructions. Flow obstructions which slow or stop water from draining will cause problems and must be removed. Usually flow obstructions are caused by debris blocking screens, ditches, and culverts. These areas must be inspected after hard rains and any obstructions removed. Some flow obstructions have been built into the system, and the drainage system should be checked and updated for the correct grades, sizes, and types of structures.

d. Slides. A slide is caused most commonly by movement of an earth mass down an inclined plane lubricated by seepage of storm runoff or by ground water (fig 7-6). The slippage plane is usually the surface of an impervious soil or rock layer where ground water is collected and trapped. Slides usually result from saturation of steep cuts or fill slopes. They may also result from ground water, frost action, weathering, vibration from blastin, excavation at toe of slope, or other mechanical disturbances. Repair of slides is discussed in paragraph 6-5c(2).

e. Construction deficiencies. Construction deficiencies arise from the original construction either not being built to meet specifications or that the specifications were not sufficient. This type of distress would include structures built on the wrong grade or slope, or sections of a structure not properly placed on relation to each other.

f. Material deficiencies. These deficiencies are caused by using an inappropriate or defective material for a job. The use of the wrong gradation for a filter and understrength concrete are two examples of possible material deficiencies.

g. Depressions and ponding areas. Depressions and ponding areas cause distress in that they gather and/or hold water. This water can cause skid-resistance and visibility problems, and if it is able to penetrate below the pavement surface, it will damage the subgrade.

7-4. Methods of maintenance and repair of drainage structures

The methods and criteria for design of surface and subsurface drainage and erosion control facilities are presented in TM 5-820-1, TM 5-8202/AFM 88-5, chapter 2; TM 5-820-3/AFM 88-5, chapter 3; TM 5-820-4/AFM 88-5, chapter 4; and the NAVFAC DM-5. Properly designed drainage, both surface and subsurface, is vital to maintenance and repair of pavements.

a. Inspection. A drainage system will be maintained so that it can function efficiently at all times.

Figure 7-6. Slide failure or collapses of a steep slope.

This goal can be obtained through adequate maintenance inspections of the structures, with careful attention to the removal of debris and prevention of erosion. Periodic inspection and evaluation of drainage facilities before, during, and after storms are considered invaluable in identifying problem areas, determining causes of malfunction and/or failures as well as aiding in determining effective methods of maintenance and repair. Periods of dry weather will be utilized in improving the drainage systems and correcting and preventing drainage failures. Any deficiencies in the original drainage system layout will be corrected immediately. Frequency of regular inspections varies with amount and intensity of rainfall and with adequacy and conditions of drainage facilities. As a minimum requirement, a complete inspection will be made in the fall in preparation for the winter season, and another in the spring to determine the extent of repair required. Inspection will also be made after any unusually heavy rainfall. All deficiencies will be noted and reported immediately to the activity engineering department.

b. Maintenance. The frequency and degree of maintenance required will vary greatly depending on the type of structure being maintained.

(1) *Mowing.* Periodic mowing of side slopes and adjacent areas of ditches and channels are required for maintaining desirable vegetation cover and control of erosion and carrying capacity. Caution should be exercised during mowing to prevent damage to cleanouts and outlets.

(2) *Cleaning and shaping*. Cleaning and shaping of drainage channels and shoulders are desired for proper drainage. Snow and ice can prevent proper drainage by blocking drainage structures and impending flow.

(a) Drainage channels. Channels will be provided with side slopes no steeper than 1 on 3. Inverts will be well above the local water table to facilitate easy access and use of conventional maintenance machinery. In areas with high groundwater levels, bottoms of channels may be located 1.5 to 2 feet below the ground-water level to prohibit growth of bottom supported vegetation. Some success has been achieved using composite channels with relatively narrow, shallow paved inverts and grassed side slopes again no steeper than 1 on 3 (1 on 4 preferred when mowing is required). The paved invert conveys low flows with velocities high enough to prevent deposition of fine-grained soil and small debris. The relatively flat-sided slopes are easily mowed and, with proper fertilization, can maintain a stable vegetation cover (fig 7-7).

(b) Shoulders. Shoulders will be kept smooth and graded so that water is drained away from the pavement toward the ditch. On a paved or surfaced road, new material will be brought in to replace any shoulder material eroding away. Any unnecessary blading or cutting, in the cleaning and shaping, that destroys the natural ground cover will be avoided. Vegetation will be developed where soil and moisture conditions are suitable, or an appropriate protective cove(ring will be provided to prevent erosion. Shoulders will be bladed flush to the edge of the pavement to avoid ponding and water seepage into the subgrade. If this is not feasible, outlets will be provided for water obstructed by high shoulders.

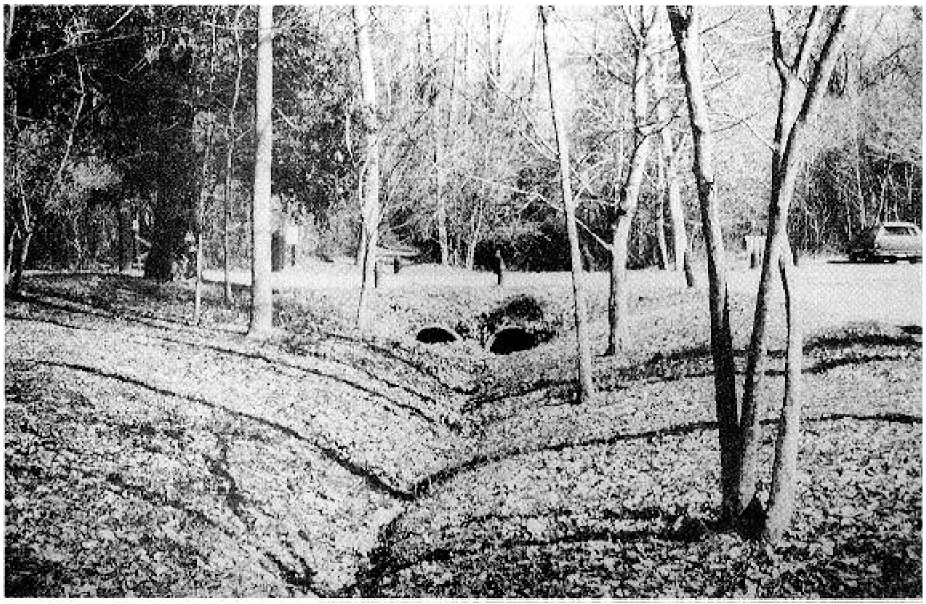

Figure 7-7. Relatively mild side slopes and good vegetative cover.

Stone-filled French drains, normal to or at a downgrade angle from the road or runway, also aid in runoff where heavy precipitation is a seasonal occurrence. Such drains help minimize rutting or washout of shoulders and consequent weakening of pavement edges, thus reducing later repair requirements for materials, labor, and time. Care will be taken to assure that these drains are not blocked with sediment and soil, or they will not function adequately.

(c) Snow. If there are accumulations of snow, special attention will be given to drainage maintenance during thaws. Side ditches will be cleared of snow, and channels will be opened through snow accumulations on the shoulder to permit water to escape into the ditches. Every precaution will be taken to prevent meltwater from ponding on pavements, on the shoulders, and in side ditches. Culverts and drains will be kept free of ice and snow.

(3) *Removing deleterious materials*. Deposition of debris and soil in channels are a common problem that notably impairs drainage capacity and requires considerable maintenance. After severe or large volume rains, all drains, culverts, channels, and screens should be inspected and cleaned if debris exists. A blocked culvert or drain can cause problems during a rain and may necessitate immediate cleaning or clearing.

c. Repair methods. Various methods are used to repair various structures involved.

(1) *Terraces and levees*. Terraces and levees are used to control water. A failure by these during high water can cause extreme damage. These structures must be inspected and analyzed for stability against failure and corrected if found deficient. When erosion or slides occur, the structures will be stabilized and repaired immediately.

(2) *Check dams or drop structures*. These devices are used to slow or control the speed of water runoff. The slopes of channel and ditch bottoms will be controlled by rock sills, ditch checks, and/or drop structures. Particular care will be taken to spread waste or spoil removed by channel construction and cleaning operations so that it blends into the local topography and prevents concentration of runoff, which may cause severe erosion and/or sloughing of the side slopes.

(3) *Headwalls and endwalls*. Headwalls prevent severe erosion of scour of the embankment adjacent to culvert inlets; they are particularly advantageous in preventing saturation and seepage of water through embankments, which results in sloughing and piping of the embankment soil (fig 7-8). Headwalls add to or help control flow and also stabilize a fill slope. Endwalls prevent the downstream end of the pipe from being undermined and also protect the embankment as do headwalls from sloughing and piping (fig 7-9). Piping will be minimized by providing proper compaction of fine-grained soils, headwalls, cutoff walls, and watertight joints along the culvert barrel and/or by providing a filter around the outlet on the downstream embankment slope. It is difficult to determine where water will go in areas where vegetation is sparse and terrain is flat. Piping is also relevant to the stability of terraces. It is desirable to provide both headwalls and endwalls on the inlets and outlets of all culverts.

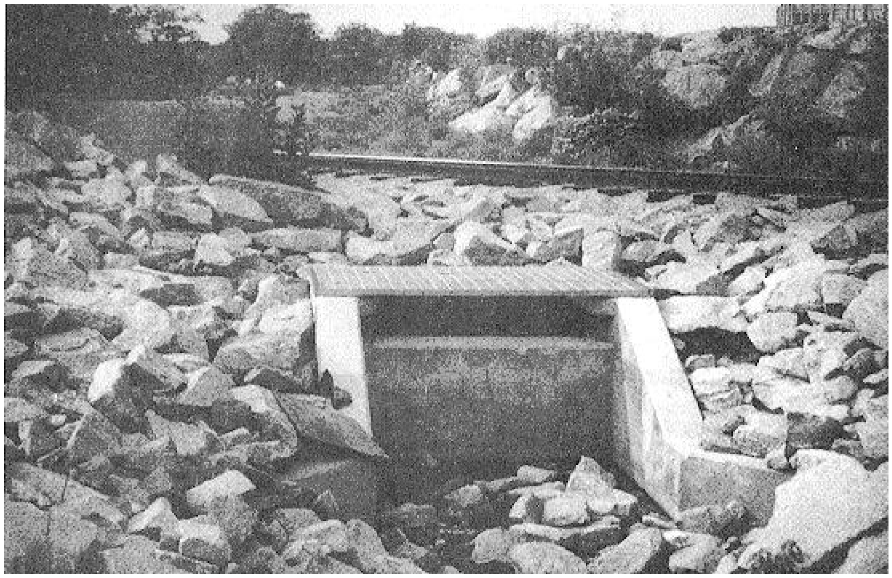

Figure 7-8. Headwall at inlet to culvert passing beneath a railroad bed.

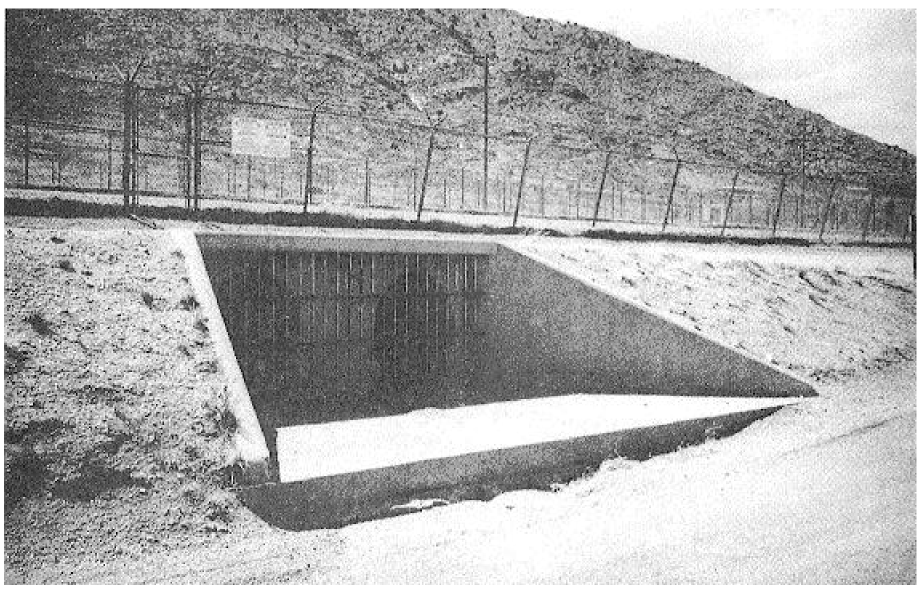

Figure 7-9. Barred concrete endwall for conveying runoff.

(4) *Riprap*. Riprap is randomly placed stones that provide protection against water erosion. Varying degrees of success have been experienced with riprap and/or rubble or other forms of protection downstream of outlets. Different opinions regarding the adequacy of protective stone have been developed. Riprap protection will be provided adjacent to all culverts and structures founded in erodible soils to prevent scour at the ends of the structures. In the placing of riprap, care will be given to selection of an adequate size stone, use of an adequately graded riprap, provision for a filter blanket, and proper treatment of the end of the riprap blanket. Figure 7-10 presents curves for the selection of the maximum size stone required to protect against the velocities indicated. Two curves are given: one to be used for riprap subject to direct attack or adjacent to hydraulic structures such as side inlets, confluences, and energy dissipators where velocity and turbulence levels are high, and the other for riprap on banks of a straight channel where flows are relatively quiet and parallel to the banks (fig 7-11).

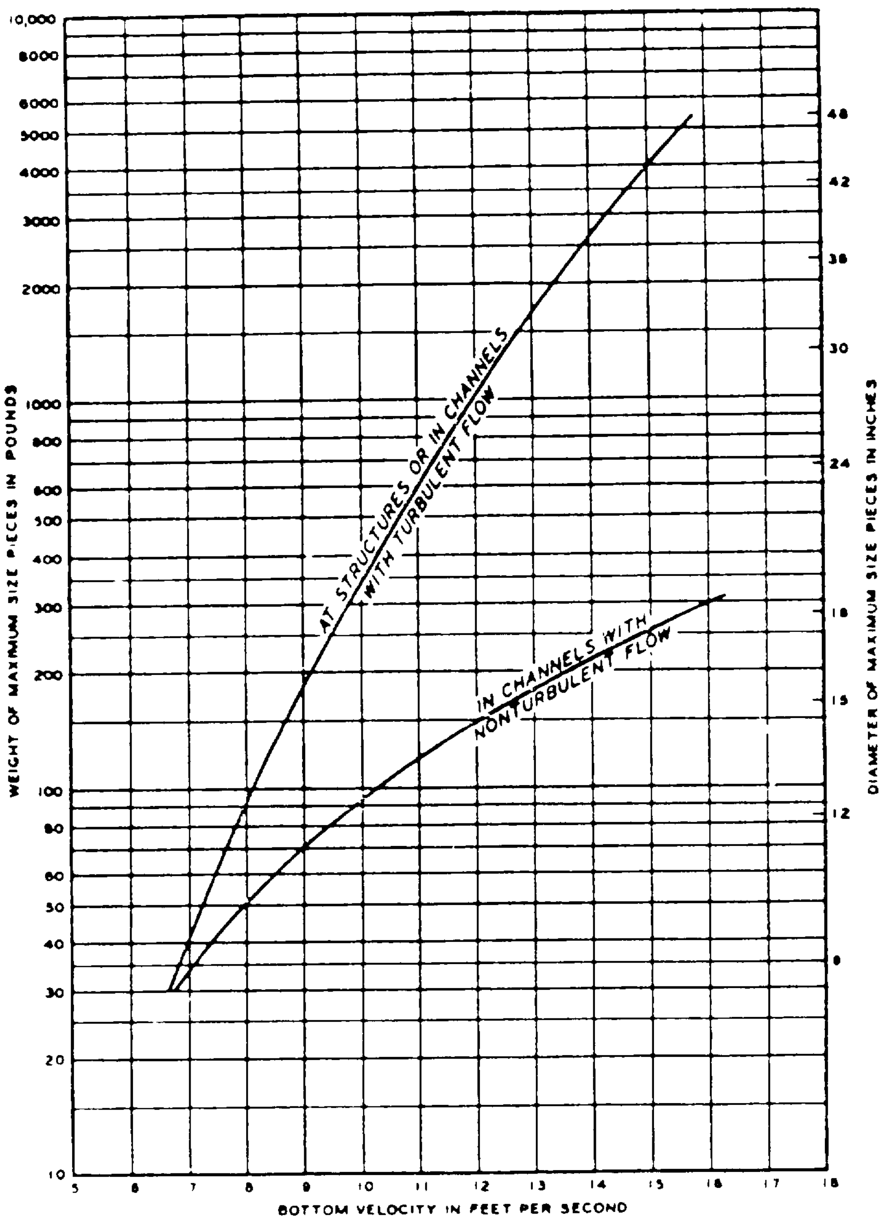

Figure 7-10. Recommended riprap sizes.

The thickness of the riprap blanket will be equal to the longest dimension of the maximum size stone required. Where the use of very large rock would be desirable but impractical, substitution of a grouted section of smaller rock may be appropriate. Grouted riprap will be followed by an ungrouted section. Grouted riprap does not perform satisfactorily in areas subject to repeated freezing and thawing. Whenever grouted riprap is installed, plans will include appropriate filters and weepholes for relief of hydrostatic pressure. Failures to riprap blankets usually result from design deficiencies, especially movement of the individual stones by a combination of velocity and turbulence, movement of the natural bed material through the riprap resulting in slumping of the blanket, and undercutting and raveling of the riprap by scout at the end of the riprap blanket. Details of solutions to this problem area, in addition to those provided below, are available from appropriate headquarters.

(a) Movement of the individual riprap stone by a combination of velocity and turbulences may be controlled by use of energy dissipators, check dams, and drop structures.

(b) Movement of the natural bed material through the riprap material may result in a slumping failure of the riprap blankets.

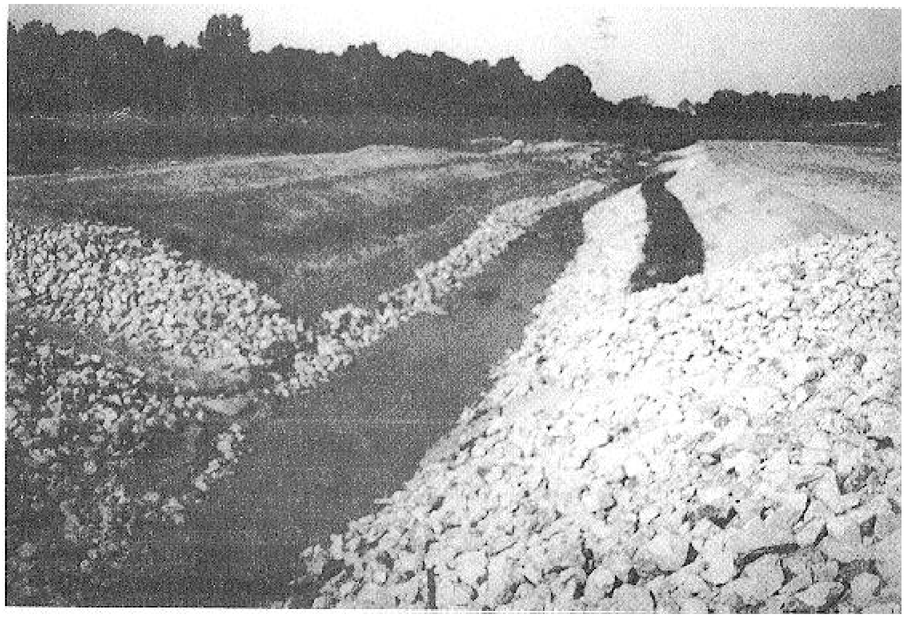

Figure 7-11. Riprap placed along a drainage channel for protection against erosion.

This problem may be controlled by the use of a sand gravel or sand and crushed rock filter or a plastic filter cloth beneath the riprap.

(c) To correct the raveling and scour that develop at the end of the riprap blanket, the thickness of the riprap blanket will be doubled at the downstream end, thereby protecting against undercutting and raveling. An alternative method involves stabilization of a scour hole by providing a constant thickness rubble blanket of suitable length dipping below the natural streambed to the estimated depth of bottom scour.

(5) *Fences*. Meandering channels, excessive sloughing, or bank erosion can be controlled by providing pervious fences of wire, rock, or wood emplaced along the toe of the side slope. Such fences will be properly anchored. The top of the fences will not extend more than 2 or 3 feet above the bottom of the channel (fig 7-12 and 7-13).

(6) *Culverts and inlets*. Culverts and storm drain inlets will be inspected frequently and kept clean of debris, sediment, and vegetation. Debris barriers will be provided upstream of open inlets in areas where debris and similar materials are present in the drainage basin (fig 7-14). The size and spacing of bars of grated inlets are usually determined by the traffic and safety requirements of the local area; however, it is desirable, in the interest of hydraulic capacity and maintenance requirements, that the opening be made as large as traffic and safety requirements will permit. The provision of a paved apron around the perimeter of a grated inlet is beneficial in preventing differential settlement of the inlet and erosion of the adjacent area; it also makes for easier mowing. Soil infiltration through pipe sections in culverts and drain pipes can be reduced or prevented. Bands or couplings with a 12 inch width are inadequate hydraulically and structurally for joining corrugated metal pipes on slopes steeper than 5 percent. Failures have not occurred where 2-foot bands have been used. The use of appropriate gaskets and couplings of the same width as well as tie bars will be given consideration in joining both rigid and flexible pipes on steep slopes. The use of durable synthetic cloth filters around the joints will be considered to aid in preventing soil infiltration through pip joints. Low pressure grouting is also available for filling voids behind pipes.

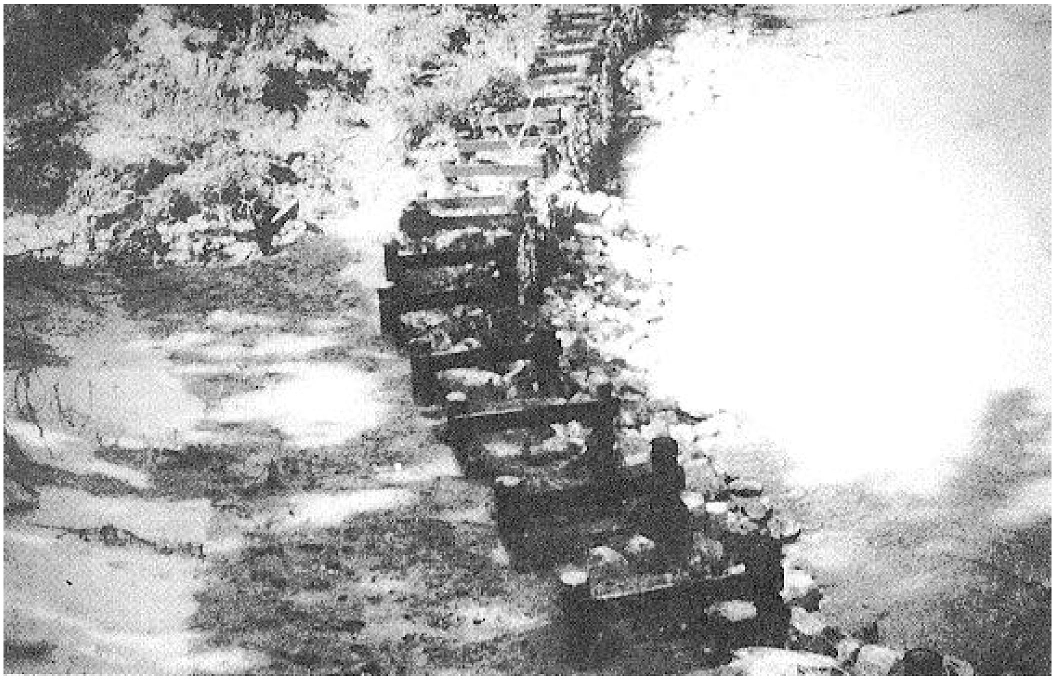

Figure 7-12. Wood and rock fencing for control of erosion.

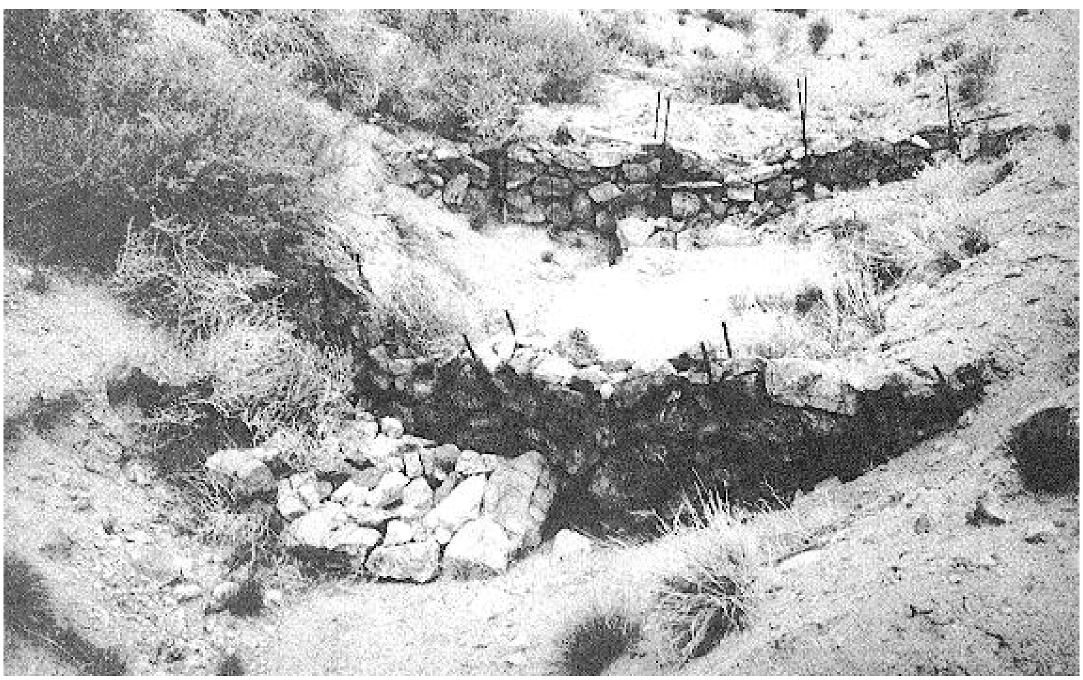

Figure 7-13. Rock fences for control of erosion.

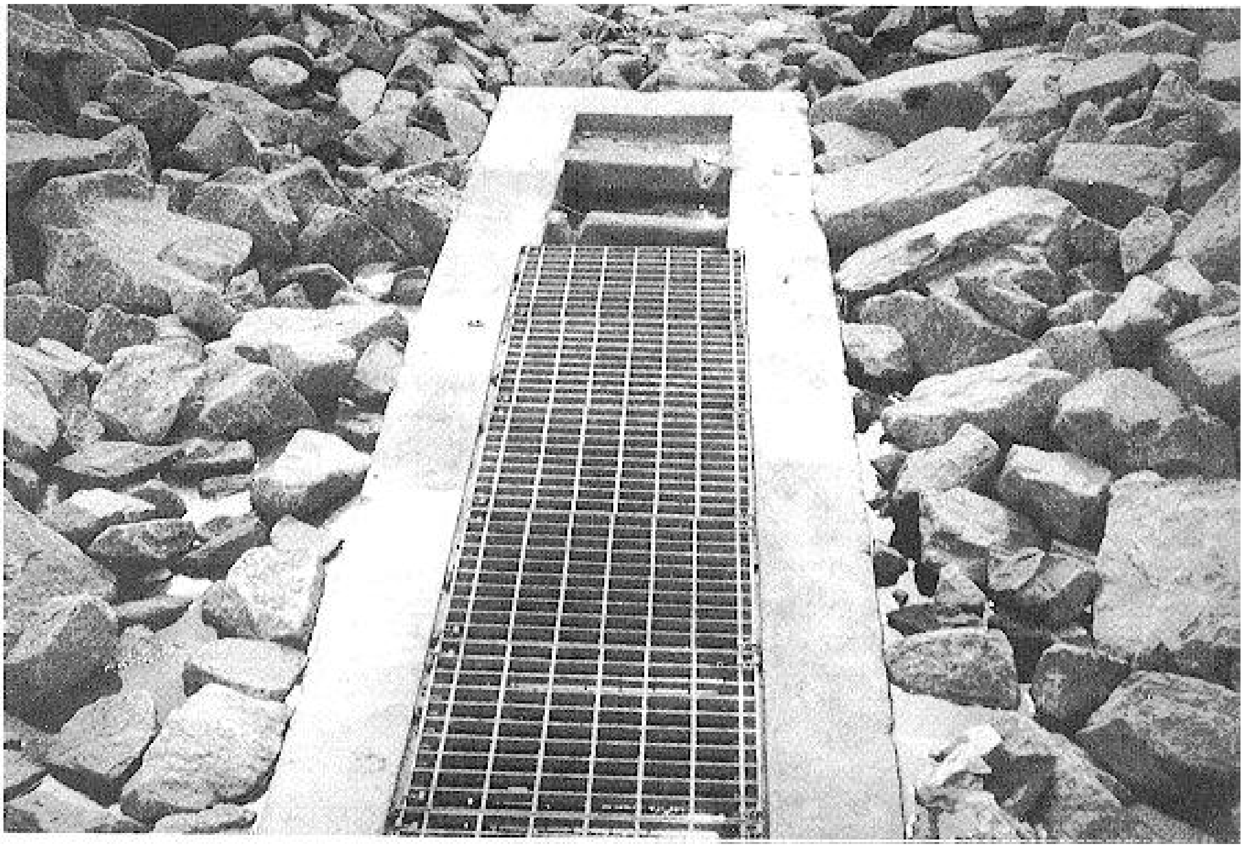

Figure 7-14. Grated inlet.