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Drainage

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Water affects many aspects of earthwork construction. In the vicinity of the construction area, surface or subsurface water needs to be controlled by some type of drainage system. Controlling usually means removing, but there are some instances in which water is needed to facilitate construction, for example, to increase compaction efficiency (Chapters 3 and 4) or to maintain vegetative growth (Chapter 8).

Controlling water on the construction site is one of the contractor's major concerns, but it tends to be neglected because often the drainage work is not a pay item. However, good drainage helps the contractor produce a more acceptable project; therefore, the contractor's profit should be increased. A job that controls erosion and stays out of the mud is much easier to run and much more efficient. Drainage is important because

1. Soils that are too wet or too dry cannot be efficiently compacted to specified densities.
2. Most soils lose strength when they are wet, that is, above optimum moisture, and both the stability of cut and fill slopes and the operation of equipment at the construction site are adversely affected.
3. Erosion can damage adjacent property.

BASIC DRAINAGE PRINCIPLES

The basic principles of drainage are as follows:

1. Water runs downhill.
2. Gravity is cheaper than plumbing.
3. Erosion depends on water velocity.
4. Erosion problems are easier to prevent than to fix later.

The aspects of drainage that affect earthwork construction are discussed in this chapter. Included are control of erosion of side slopes, ditches, and the basins at the ends of culverts; sedimentation control measures, including detention ponds; and subsurface water and underdrains.

SURFACE WATER

It is important to remove surface water from the embankments as quickly as possible to prevent it from being absorbed by the near-surface materials. Surface waters should also be controlled to prevent erosion, and if erosion occurs in spite of attempts to prevent it, the eroded soil particles should be encouraged to settle out of the runoff. The plans and specifications will almost always include permanent surface water control features (primarily ditches) to protect the finished facility; however, additional surface drainage systems will also be needed during construction. These as well as all other drainage items should be put in place as soon as possible, as they will simplify subsequent construction.

The area surrounding the site should also be considered because it may be possible to check erosion by retarding the flow of water onto the site or to prevent any water from encroaching on the site. This may not be easy to do on roadway widening projects, however. Runoff from the existing pavement and changes to drainage systems often make the problem worse on existing pavement than on new construction. It is false economy to allow slopes or drainage paths to erode badly, even though the contractor may be required to pay later for repairs as well as stabilization (HRB 1952).

Erosion

The detrimental effects of erosion can be minimized by understanding the erosion process and taking prompt and correct remedial action. The amount of erosion that takes place depends on (a) the velocity of the water that flows over the surface, (b) the type of soil or material that the water flows over, and (c) the vegetative cover. The relationship between the velocity of water and erosion is very important. Doubling the velocity of water will increase its erosive energy by four times, the size of particle that can be carried by 64 times, and the mass of soil that can be transported by 32 times (Israelson, 1980a). Thus, if job site erosion is to be prevented, certain characteristics that affect velocity must be kept in mind:

1. Slope—the steeper the slope, the faster water will flow.

2. Roughness of the slope channel—the smoother the channel, the faster water will flow.

3. Depth of flow—the deeper the flow over a surface, the faster it will flow.

4. The shape of the flow channel—the smaller the channel surface area in contact with the water, the faster the flow.

5. Quantity of flow—the larger the quantity, the faster the flow.

These characteristics lead to the prime rule of erosion control: do not allow water to concentrate; keep it dispersed whenever and wherever possible.The erodibility of a slope also depends on the type of soil and vegetation cover. Loose noncohesive soils tend to be more prone to erosion than dense cohesive soils. Fine sands and silts are the most erodible. Vegetation tends to decrease soil erodibility.

The contract plans and specifications will detail any required erosion control measures. The basic philosophy of some of the more common erosion control measures is explained in the sections that follow.

Control of Erosion on Side Slopes

The most critical time for slope erosion is immediately after the start of excavation or embankment construction. The soil on the surface is loose and is exposed to rainfall, and vegetation has not yet taken hold. A typical raindrop travels about 19 mph, and when it hits the soil surface, it displaces unprotected soil particles and starts washing them downslope (FHWA 1976; Israelson 1980a). The following measures should be taken to prevent side slope erosion:

1. Protect the newly exposed slope from the high velocity impact of raindrops. This should be done as soon as possible; one short, intense rainfall can ruin a well-designed and constructed slope. The most common method of dissipating the energy on newly exposed soils is by mulching. The mulch absorbs the impact energy and breaks up the raindrops. Common types of mulch are hay or straw, wood chips, crushed stone, and geotextiles. Details on the quantities of mulch to use can be found elsewhere (Israelson 1980b; CCSWC 1985).

2. Do not permit excessive quantities of water from outside the construction area to flow down cut slopes. Top-of-slope ditches are an important preventive measure (see Chapter 4, section on Slope Ditches). They should be put in promptly, as the slope is most vulnerable immediately after construction. Top-of-slope ditches need to be handled carefully,

however, as they tend to be quite steep (ditch erosion is discussed in the next section.

3. Keep the side slopes as flat as possible. (Cuts in rock, loess, or other lightly cemented permeable soils are exceptions.)

4. Be sure that the water arrives on the slope in a sheet and keep it in a sheet as long as possible. This is done by constructing continuous flat or slightly rounded slopes. Eventually adjacent slopes will intersect and the water will have to be concentrated into a ditch or stream, preferably under controlled conditions.

5. Establish a dense growth of grass or other vegetation as soon as possible. Vegetation slows down the water and lowers the erodibility of the slope surface. Mulching (Item 1) protects the slope and the seed or seedlings until the vegetation takes hold. After the vegetation is established, it ordinarily will dissipate the energy of raindrops.

Control of Erosion in Ditches

The following precautions should be taken to control erosion in ditches:

1. Ditches should carry no more water than necessary. Adjacent land owners should solve their own drainage problems, if possible.
2. Ditches should carry water only as far as necessary.
3. Avoid changes in direction of flow in a ditch. Use pipes for high flows and sharp turns.
4. Do not allow water to fall into a ditch. It should enter the ditch with as little impact as possible. Check dams can be engineered to handle large flows, but drop inlets into pipes or erosion protection linings are more appropriate for small ditches.
5. Do not allow water to pond in a ditch. When this happens the ditch is not carrying out its intended drainage function.

Well-sodded ditches should be used whenever possible; however, sod needs sun and cannot be maintained in channels that approach continuous flow. Also, it may not be practical or cost effective to sod a ditch during construction.

The factors that affect the velocity of flow in ditches are the same as those mentioned previously: (a) slope, (b) ditch roughness, (c) depth of flow, (d) ditch shape, and (e) quantity of flow. Slope is difficult to control because it is dictated by the geometry of the site. Nevertheless, slopes between about 0.5 and a maximum of about 2 percent should be maintained wherever possible.

Roughness of the ditch helps to decrease velocity at low flows, but it is not as effective at high flows. The quantity and depth of flow and the ditch shape are all interrelated. The general rule is to have wide flat ditches and keep them as short as possible.

If after everything else has been considered, the water is still eroding the natural ditch lining, then an alternative lining is needed. One of the most effective linings for small ditches is a geotextile, either natural (jute) or synthetic. This design, if well constructed, will tolerate about the same water velocities as grass sod.

Stabilizing Eroded Ditches

Fast-flowing water in a ditch or stream is always turbulent, and this produces large traction forces that dislodge material from the stream bed and carry it downstream. A natural stream develops a filter system of successively smaller particles below the stream bed, which is relatively stable at normal flow velocities. Given time, ditches will also develop these same filter systems, but usually by the time a construction ditch stabilizes, large gullies or other problems will have occurred. By constructing a filter system using natural aggregate materials or aggregate materials and geotextiles, it is possible to stabilize an eroding ditch.

To be successful, filter systems must have the following characteristics:

1. The aggregate or stones in the top layer must be large enough to resist the water traction forces.
2. The particles in each successive lower layer are smaller than those in the layer above, but they are too large to pass through the voids in the layer above it.
3. Each layer must allow water to freely pass through it.

In many cases a two-layered system is all that is needed, although sometimes three aggregate layers are required. Geotextiles can be used in place of one or more of the finer filter aggregate layers (Christopher and Holtz 1985), but for permanent installations, the geotextile may need to be protected by a layer of gravel between it and large stones on the ditch bed. Riprap used to protect stream beds and slopes adjacent to water bodies require granular filters or geotextiles and should be constructed accordingly.

Culvert and Pipe Outlets

Because water leaving culvert and pipe outlets is concentrated and usually traveling at velocities that will erode the natural stream bed, these features are of particular concern. In most cases, construction of a filter system that includes riprap from the outlet to a point downstream where the stream velocity is harmless will solve the problem.

In severe cases, stilling basins together with filters are needed. Care must be taken to protect the natural material at the edges of stilling basins until water velocities become tolerable. Placing large rocks or riprap at the ends of pipes (or in other parts of a stream bed that is experiencing erosion problems) without providing a filter underneath is not the way to solve the problem. Eventually the stream will form its own stilling basin and filter, but usually this will not happen until after some detrimental erosion has occurred.

SEDIMENT CONTROL

Sediment is the soil material that settles out of a dilute mixture of soil and water. Sediment will separate from the water when the velocity is slowed to a level that will no longer carry or move the soil particles. Environmental Protection Agency regulations require that material that has been eroded on a construction site must be retained within the bounds of the construction area.

Sedimentation control is needed on a construction site because of the inability of the contractor's erosion control practices to prevent all erosion. Sedimentation of material from water is not necessarily easy, and it is usually false economy to allow erosion to take place and then try to recover the materials.

All sedimentation control facilities must perform three functions: (a) decrease the velocity of the water to a level that will allow the suspended material to settle, (b) retain the water for a sufficient time for settling to take place, and (c) release the water without causing erosion or flooding downstream.

Because sedimentation control measures must decrease the velocity of the water in a stream or ditch, the size and extent of the facilities required are directly related to the quantity and duration of flow. The simplest sedimentation control measures, straw bales and geotextile silt fences, can be used on smaller swales and ditches when the flow is intermittent. Larger continuous flowing ditches or streams require detention ponds and barrier structures, as discussed in the next section.

Straw bales and silt fences are not complicated structures, but to function successfully they must be properly constructed and maintained. These barriers are designed to allow the water to seep through the material. Water must not be allowed to flow around the edges or under silt barriers, or flow over the top in a concentrated high velocity flow. The channel downstream of the barrier should be constructed to carry the flow without allowing further erosion to take place. The ditch section just beyond the silt barrier may need erosion protection similar to that used at culvert outlets.

Any required periodic maintenance should be detailed in the contract specifications. For example, to ensure that the velocity is slowed and that there is sufficient storage in case of a storm, the backwater area must be cleaned if the deposited material comes halfway up the height of the barrier. Any damage or displacements in the barriers should be repaired immediately. Clogged barriers should be replaced.

Detention ponds should be treated as major features, and the plans and specifications for the barriers should be followed closely. The barrier is a dam and should be designed and constructed as such. Failures of these structures could cause major downstream damage. Areas of particular concern are

1. *Construction of the embankment.* Density and material requirements for different parts of the structure should strictly follow the plans and specifications.
2. *Location and construction of the emergency spillway.* This is essentially a large steep ditch and the necessity of including a good filter system cannot be overemphasized. Failures of spillways can cause rapid erosion and loss of the retention structure. A stilling basin or other method of dissipating the energy of fast flowing water is needed at the base of the spillway to reduce the velocity of the discharge to the receiving stream.
3. *Installation of pipe conduits that extend through the embankment and act as a spillway and pond drain.* Because a pipe through an embankment is a major discontinuity, seepage between the embankment and the pipe is a potential source of failure. It must be controlled by the careful compaction of select material around the pipe and by the installation of seepage collars at specified lengths along the pipe.

SUBSURFACE WATER

The emergence of subsurface water is of concern on the construction site because it affects the strength and load-carrying capacity of the soil; it is a factor in almost all failures of soil slopes and excavations. Because the original source of the subsurface water is rain that has fallen somewhere upslope of the site, careful observation of the area surrounding the site will usually indicate the source of the subsurface water problem.

Underdrains

Subsurface water is generally removed with underdrains such as trench or French drains. Although these drains are easy to design, they are difficult to construct without segregation of the granular filter or contamination of the filter and drain aggregate. As a result they are often not as effective as they should be.

Today, most underdrains are constructed using either geotextiles to replace the graded granular filter materials or with prefabricated geocomposite drains, which greatly simplify construction operations. To ensure that the geotextile or geocomposite will work as designed, however, several important points must be kept in mind when installing them. They should be protected from dirt and contamination, exposure to sunlight, and damage during shipping and storage. Installation and backfilling must be carefully done to avoid tearing or puncturing the geotextile. If the drain is a geocomposite, care must be taken to avoid damaging the core. Finally, the drainpipe and its outlets must be properly located. See *Geotextile Engineering Manual* (Christopher and Holtz 1985) for additional information about using geotextile filters and geocomposites in underdrains.

Common Subsurface Drainage Problems

Sometimes unanticipated subsurface water problems occur during construction or maintenance. For example, shallow slope failures can occur because of subsurface water seeping from a slope or moving parallel to and near its surface. Three possible solutions are

1. Install one or more subsurface drains to lower the groundwater surface. These drains may also help to prevent deeper slope failures. A drain at or near the ditch line will also tend to increase the strength of the roadway subgrade.
2. After undercutting, place a thick blanket of stone or rock on the slope. Although this will help to prevent shallow slope failures, it will not increase the strength of the roadway subgrade nor will it help prevent deeper slope failures.
3. Flatten the slope so that the wet slope is stable.

If the roadway is unstable because of free water at or near the surface, often it is possible to solve this problem by crowning the roadway and constructing deeper side ditches to remove the surface water and to lower the water table below the roadway. After crowning the roadway and constructing side ditches, subsurface drains can be installed to further lower the water table. It may not be necessary to install these drains on both sides of the roadway. This method may be too slow to be helpful on a construction job because it may take too long to actually lower the water table. However, over the long term, this installation may be necessary to ensure a more stable roadway foundation. In this case, request advice from the engineer.

Another solution would be to install a geotextile and aggregate surface on the crowned and ditched roadway. This will permit the water to drain from the subgrade while preventing the subgrade material from intruding into the coarse stone subbase layers. The aggregate layers must be permeable so that they will remain stable when wet. Note that these solutions assume that corrective action can be taken without changing the grade of the roadway. If this is impossible, see Chapter 4, section on Unsuitable Materials.

If an excavation for a structure foundation is unstable because the original groundwater table is above the bottom of the excavation, side ditches can be constructed around the periphery of the excavation to lower the water table. The ditches must drain to a sump where the water can be pumped from the excavation.

A geotextile-aggregate mat thick enough to provide a stable working surface can be installed. The peripheral ditches with the sump pump are also needed. The aggregate mat needs to be permeable to internally drain water to the peripheral ditches and to remain stable when wet.

Well points around the periphery of the base can be installed to lower the free water surface to produce a stable base. The required spacing, usually between 3 and 12 ft, depends on the type of soil and the desired depth of groundwater lowering (Cedergren 1989). Again, these solutions assume no change in the elevation of the bottom of the structure foundation.

REFERENCES

ABBREVIATIONS

CCSWC Connecticut Council on Soil and Water Conservation
FHWA Federal Highway Administration

CCSWC. 1985. *Connecticut Guidelines for Soil Erosion and Sediment Control.* Connecticut Council on Soil and Water Conservation, State Office Building, Hartford.

Cedergren, H. R. 1989. *Seepage, Drainage, and Flow Nets,* 3rd ed. Wiley, New York, N. Y., pp. 254–291.

Christopher, B. R., and R. D. Holtz. 1985. *Geotextile Engineering Manual.* Report FHWA-TS-86/203. FHWA, U. S. Department of Transportation, 1024 pp.

FHWA. 1976. Erosion Measurements for Roadway Slopes. *Water Quality Manual.* Implementation Package 77-1. U. S. Department of Transportation.

HRB. 1952. Erosion Control—Trends and Techniques. *Highway Research Circular 156: Roadside Memorandum Series 2.* National Research Council, Washington, D. C.

Israelson, C. E. 1980a. *NCHRP Report 220: Erosion Control During Construction—Research Report.* TRB, National Research Council, Washington, D. C.

Israelson, C. E. 1980b. *NCHRP Report 221: Erosion Control During Highway Construction—Manual on Principles and Practices.* TRB, National Research Council, Washington, D. C.