CHAPTER 7

DRAINAGE STRUCTURES

7-1 **GENERAL.** Certain appurtenant structures are essential to the proper functioning of every storm drainage system. These structures include inlet structures, manholes, and junction chambers. Other miscellaneous appurtenances include transitions, flow splitters, siphons, and flap gates.

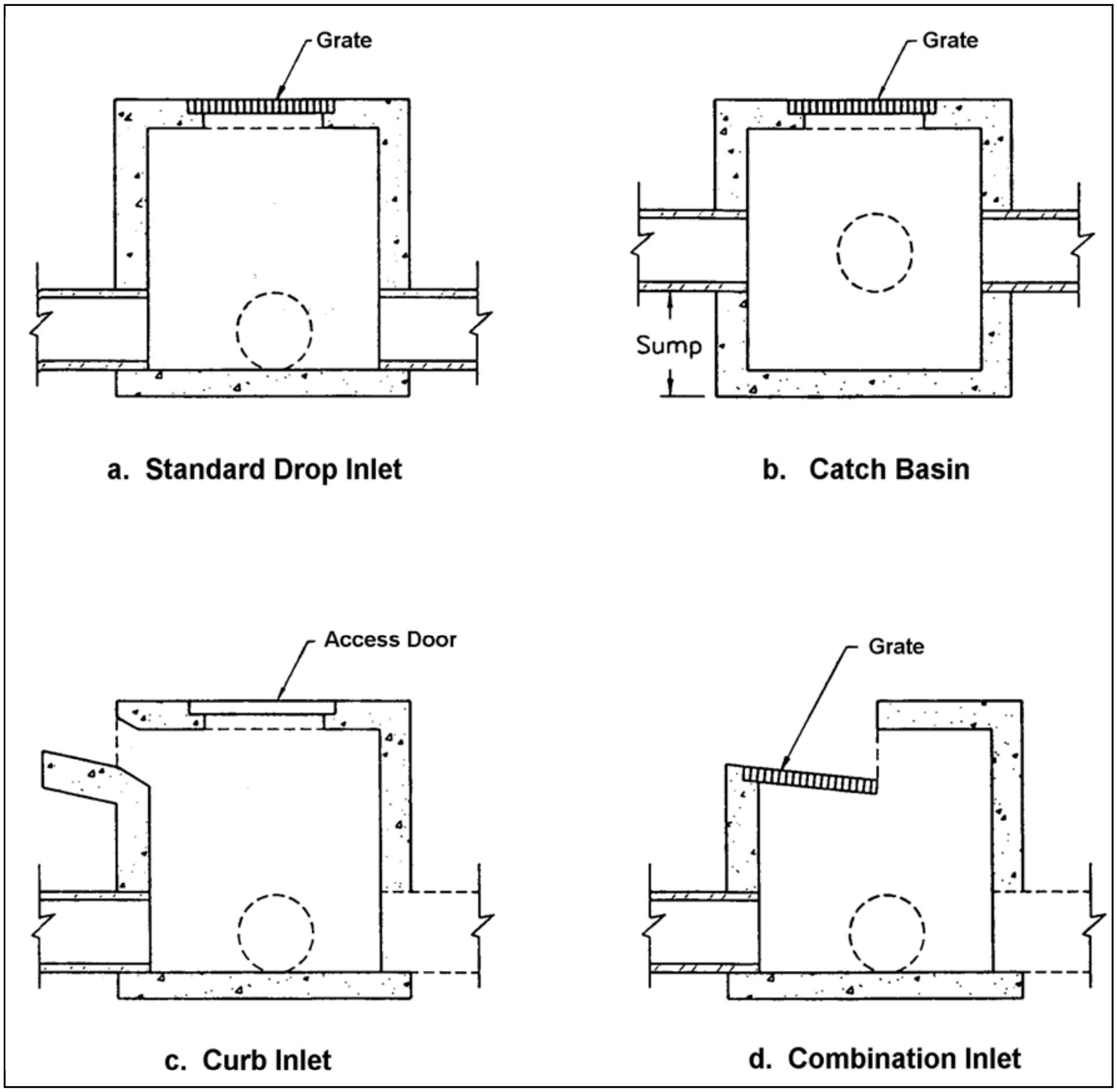
Many agencies have developed their own design standards for commonly used structures; therefore, it is to be expected that many variations will be found in the design of even the simplest structures. The information in this chapter is limited to a general description of these structures with special emphasis on the features considered essential to good design.

7-2 **INLETS.** The primary function of an inlet structure is to allow surface water to enter the storm drainage system. As a secondary function, inlet structures also serve as access points for cleaning and inspection. The materials most commonly used for inlet construction are cast-in-place concrete and pre-cast concrete. The structures must ensure efficient drainage of design storm runoff to avoid interruption of operations during or following storms and to prevent temporary or permanent damage to pavement subgrades. The material, including the slotted drain corrugated metal pipe to handle surface flow (if employed), should be strong enough to withstand the loads to which it will be subjected.

7-2.1 **Configuration.** Inlets are structures with inlet openings to receive surface water. Figure 7-1 illustrates several typical inlet structures, including a standard drop inlet (area inlet), catch basin, curb inlet, and combination inlet. The hydraulic design of surface inlets is covered in detail in Chapter 3.

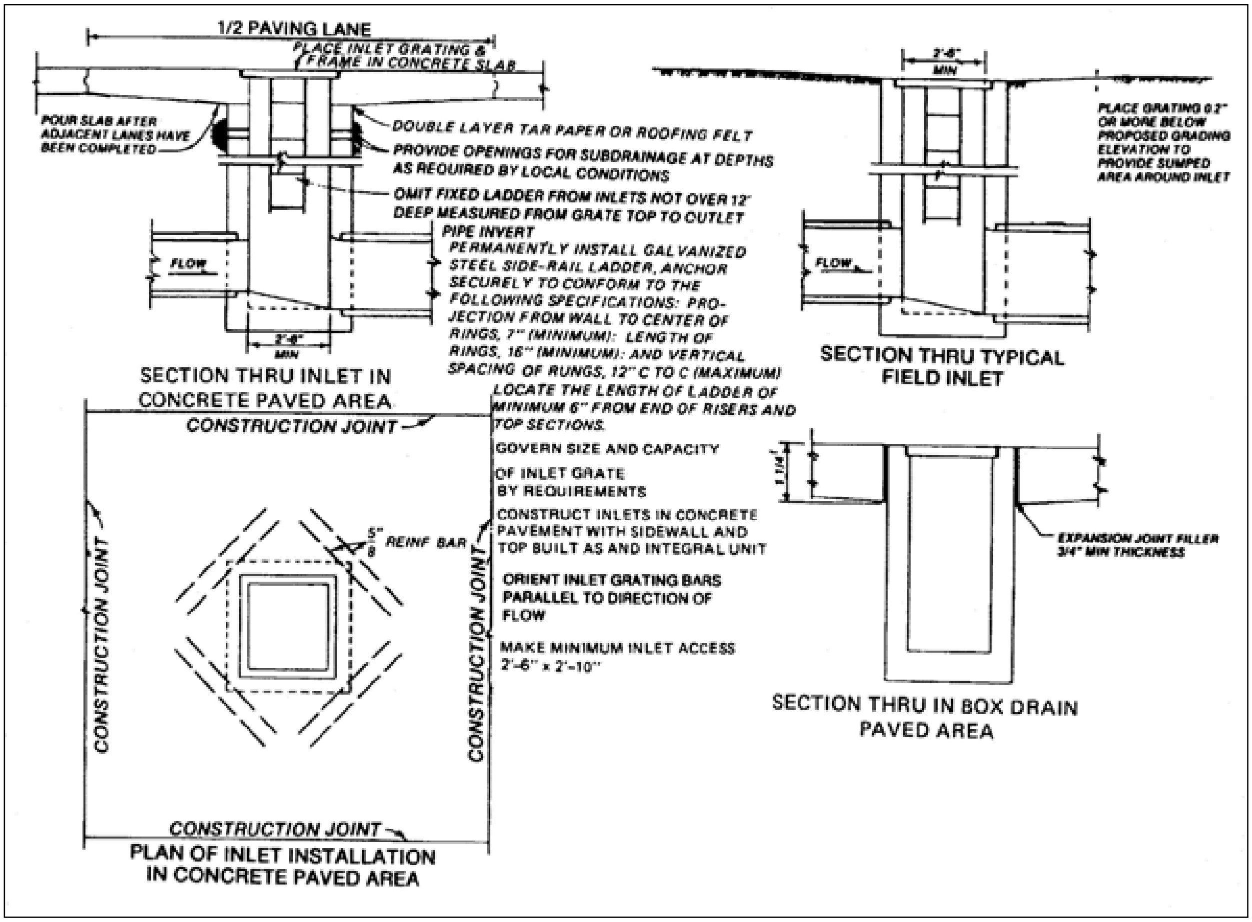
The catch basin, illustrated in Figure 7-1, b, is a special type of inlet structure designed to retain sediment and debris transported by storm water into the storm drainage system. Catch basins include a sump for the collection of sediment and debris. Catch basin sumps require periodic cleaning to be effective and may become an odor and mosquito nuisance if not properly maintained; however, in areas where site constraints dictate that storm drains be placed on relatively flat slopes, and where a strict maintenance plan is followed, catch basins can be used to collect sediment and debris but are ineffective in reducing other pollutant loadings. Additional information regarding the removal of pollutants from storm water can be found in Chapter 11.

Figure 7-1. Inlet Structures



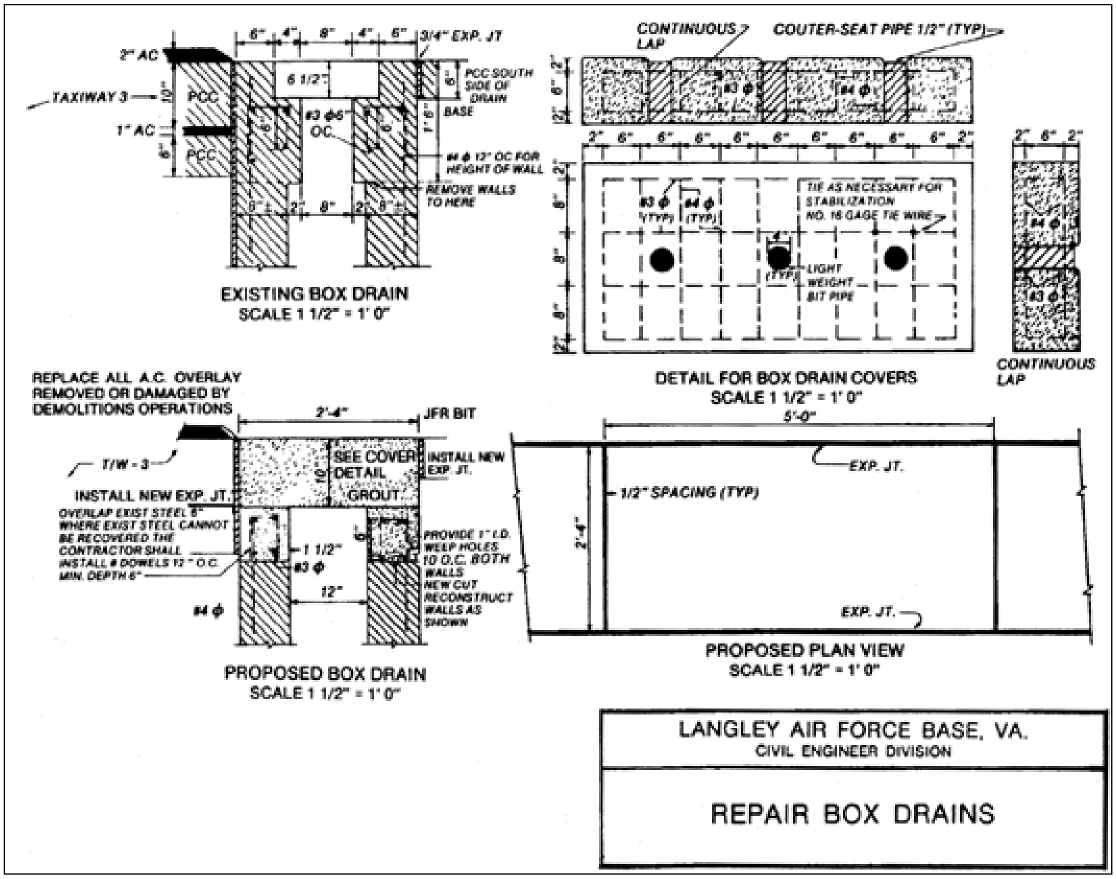
7-2.2 **Area Inlets.** Where area inlets are used within paved areas to remove surface drainage, a continuous-type grating, generally covering the entire drain, is used to permit water to enter directly into the drain. Certain general requirements are illustrated by the typical section through an area inlet in a paved area shown in Figure 7-2. The walls of the box drain will extend to the surface of the pavement. The pavement will have a free thickened edge at the drain. An approved expansion-joint filler covering the entire surface of the thickened edge of the pavement will be installed at all joints between the pavement and box drain. A 0.75-in. thick filler is usually sufficient, but thicker fillers may be required. Grating for area inlets can be built of steel, cast iron, or reinforced concrete with adequate strength to withstand anticipated loadings. Where two or more area inlets are adjacent, they will be interconnected to provide equalization of flow and optimum hydraulic capacity.

Figure 7-2. Typical Inlet Design for Storm Drainage Systems



7-2.2.1 A number of area inlets similar to those shown in Figure 7-2 have failed structurally at several installations. Causes of failure are the inability of the drain walls to resist the movement of the abutting pavement under seasonal expansion and contraction, the general tendency of the slope pavement to make an expansion movement toward the drain wall while the thickened edge is restrained from moving away from the drain, and the infiltration of detritus into joints. Figure 7-3 indicates a successful box drain in use at Langley Air Force Base. The design provides for the top of the box drain wall to terminate at the bottom of the abutting pavement. A typical drain cover is a 10-in. thick reinforced concrete slab with inserted lightweight circular pipes used for the grating openings. While only 4-in. diameter holes have been indicated in the figure, additional holes may be used to provide egress for the storm runoff. The design may also be used to repair existing area inlets that have failed.

Figure 7-3. Repair Area Inlets



7-2.2.2 Inlet drainage structures, particularly area inlets, have been known to settle at rates different from the adjacent pavement, causing depressions that permit pavement failure should the subgrade deteriorate. Construction specifications requiring careful backfilling around inlets will help prevent the differential settling rates.

7-2.2.3 Inlet structures are located at the upstream end and at intermediate points along a storm drain line. Inlet spacing is controlled by the geometry of the site, inlet opening capacity, and tributary drainage magnitude. Inlet placement is generally a trial and error procedure that attempts to produce the most economical and hydraulically effective system.

Certain general rules apply to inlet placement:

- An inlet is required at the uppermost point in a gutter section where gutter capacity criteria are violated. This point is established by moving the inlet and thus changing the drainage area until the tributary flow equals the gutter capacity. Successive inlets are spaced by locating the point where the sum of the bypassing flow and the flow from the additional contributing area exceed the gutter capacity. Chapter 3 contains information regarding inlet spacing procedures.

- Inlets are normally used at intersections to prevent street cross flow that could cause pedestrian or vehicular hazards. It is desirable to intercept 100 percent of any potential street cross flow under these conditions. Intersection inlets should be placed on tangent curb sections near corners.

- Inlets are also required where the street cross slope begins to superelevate. The purpose of these inlets is also to reduce the traffic hazard from street cross flow. Sheet flow across the pavement at these locations is particularly susceptible to icing.

- Inlets should also be located at any point where side drainage enters streets and may overload gutter capacity. Where possible, these side drainage inlets should be located to intercept side drainage before it enters the street.

- Inlets should be placed at all low points in the gutter grade and at median breaks.

- Inlets are also used upstream of bridges to prevent pavement drainage from flowing onto the bridge decks, and downstream of bridges to intercept drainage from the bridge.

- As a matter of general practice, inlets should not be located within driveway areas.

7-3 **MANHOLES.** The primary function of a manhole is to provide convenient access to the storm drainage system for inspection and maintenance. As secondary functions, manholes also serve as flow junctions, and can provide ventilation and pressure relief for storm drainage systems. It is noted that inlet structures can also serve as manholes and should be used in lieu of manholes where possible so that the benefit of extra storm water interception is achieved at minimal additional cost.

Like the materials used for storm drain inlets, the materials most commonly used for manhole construction are pre-cast concrete and cast-in-place concrete. In most areas, pre-cast concrete manhole sections are commonly used due to their availability and competitive cost. They can be obtained with cast-in-place steps at the desired locations, and special transition sections are available to reduce the diameter of the manhole at the top to accommodate the frame and cover. The transition sections are usually eccentric, with one side vertical to accommodate access steps. Pre-cast bottoms are also available in some locations.

7-3.1 **Configuration.** Typical manhole and junction box construction is shown in Figures 7-4 through 7-7. Where storm drains are too large to reasonably accommodate the typical structure configurations illustrated in Figure 7-7, a vertical riser connected to the storm drain with a commercial "tee" unit is often used. Such a configuration is illustrated in Figure 7-8. As illustrated in Figure 7-7, the design elements of a manhole include the bottom chamber and access shaft, the ladder, and the manhole bottom. The design elements of a manhole are examined in paragraphs 7-3.2 through 7-3.7.

7-3.2 **Chamber and Access Shaft.** Most manholes are circular, with the inside dimension of the bottom chamber being sufficient to perform inspection and cleaning operations without difficulty. A minimum inside diameter of 4 ft has been adopted widely, with a 5-ft diameter manhole being used for larger diameter storm drains. The access shaft (cone) tapers to a cast-iron frame that provides a minimum clear opening usually specified as 22 to 24 inches. It is common practice to maintain a constant diameter bottom chamber up to a conical section a short distance below the top, as shown in Figure 7-7, a. It has also become common practice to use eccentric cones for the access shaft, especially in precast manholes. This provides a vertical side for the steps (Figure 7-7, b), which makes the manhole much easier to access.

Another design option maintains the bottom chamber diameter to a height sufficient for a good working space, then tapers to 3 ft as shown in Figure 7-7, c. The cast iron frame in this case has a broad base to rest on the 3-ft diameter access shaft. Still another design uses a removable, flat, reinforced concrete slab instead of a cone, as shown in Figure 7-7, d. As illustrated in Figure 7-7, the access shaft can be centered over the manhole or offset to one side. Certain guidelines apply:

- For manholes with chambers 3 ft or less in diameter, the access shaft can be centered over the axis of the manhole.
- For manholes with chambers 4 ft or greater in diameter, the access shaft should be offset and made tangent to one side of the manhole for better location of the manhole steps.
- For manholes with chambers greater than 4 ft in diameter, where laterals enter from both sides of the manhole, the offset should be toward the side of the smaller lateral.
- The manhole should be oriented so the workers enter it while facing traffic if traffic exists.

7-3.3 **Frames and Covers.** Manhole frames and covers are designed to provide adequate strength to support superimposed loads, provide a good fit between cover and frame, and maintain provisions for opening while providing resistance to unauthorized opening (primarily from children). Additional information specific to airfields is located at the end of this chapter. In addition, to differentiate storm drain manholes from those on sanitary sewers, communication conduits, or other underground utilities, it is good practice to have the words "STORM DRAIN" or equivalent cast into the top surface of the covers. Most agencies maintain frame and cover standards for their systems. Special considerations for aircraft loading are provided at the end of this chapter.

Figure 7-4. Standard Storm Drain Manhole

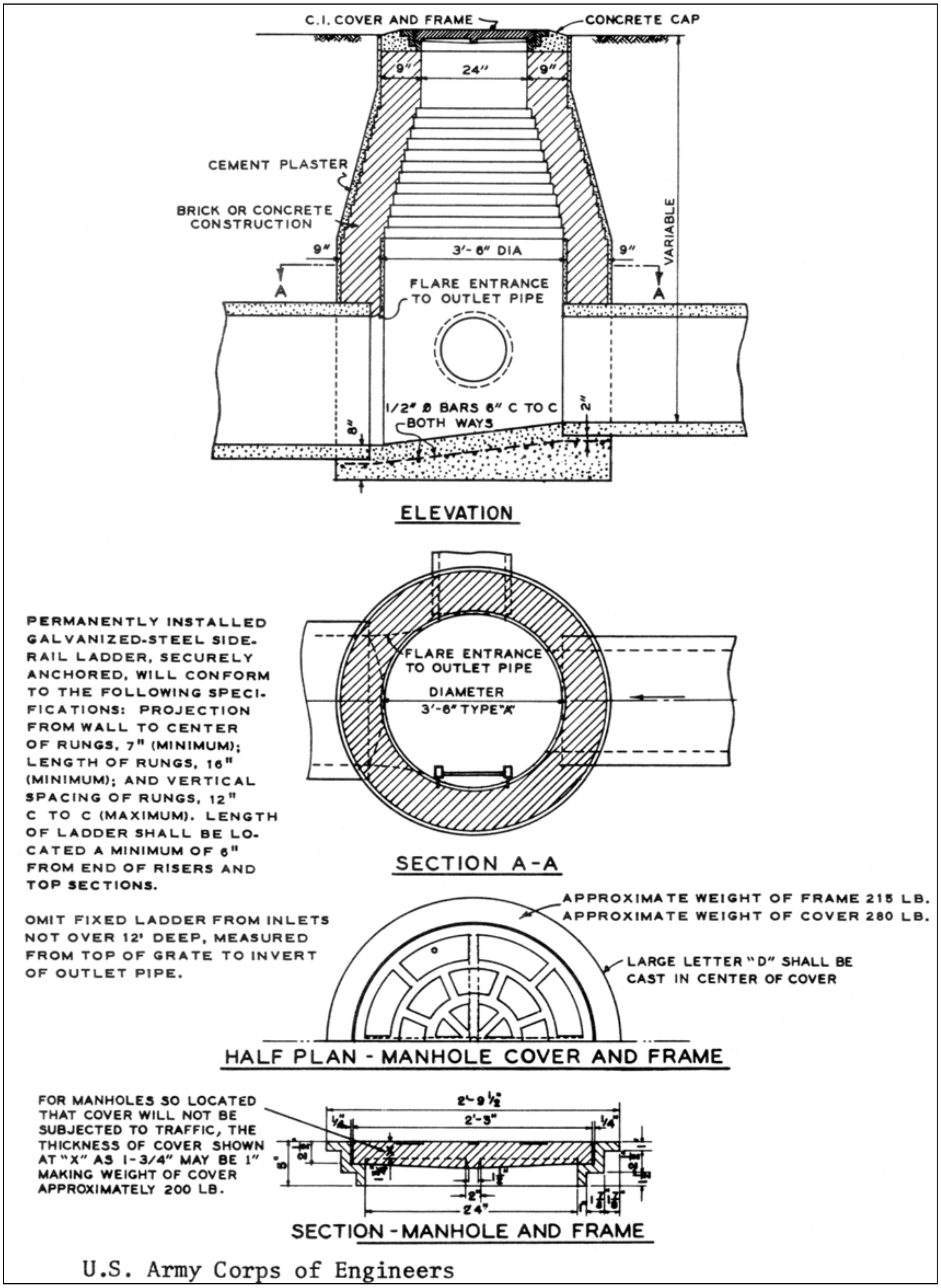


Figure 7-5. Standard Precast Manholes

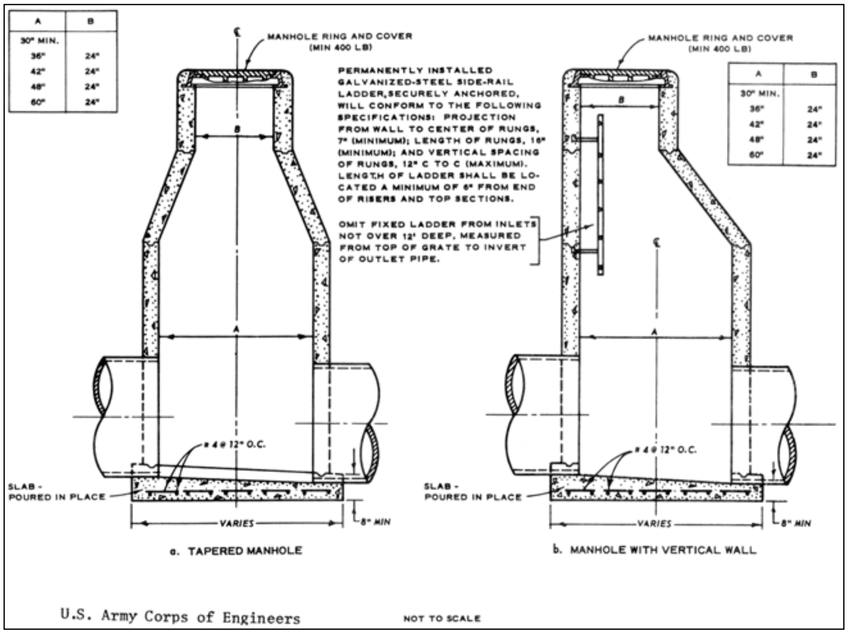


Figure 7-6. Junction Details for Large Pipes

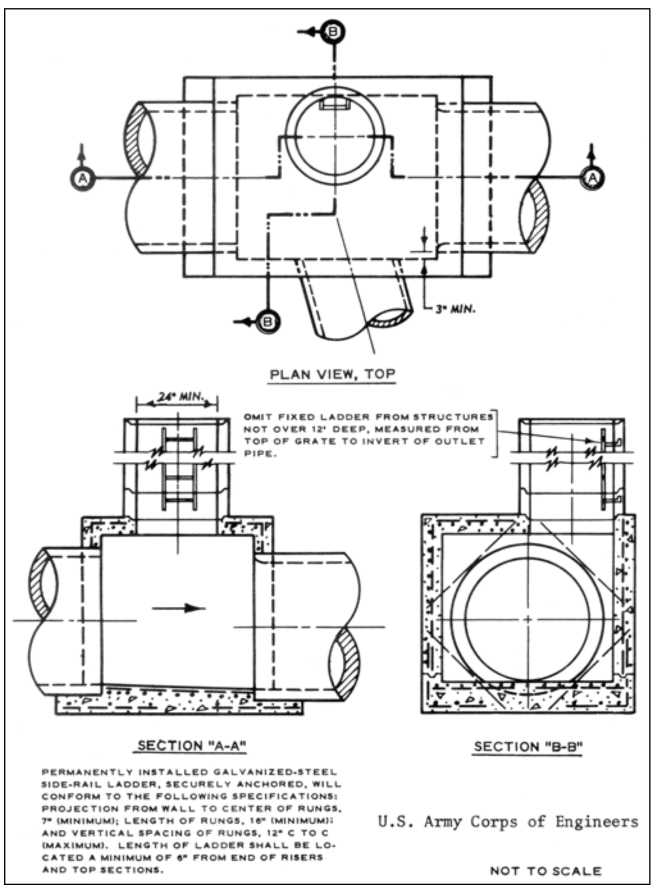


Figure 7-7. Typical Manhole Configurations

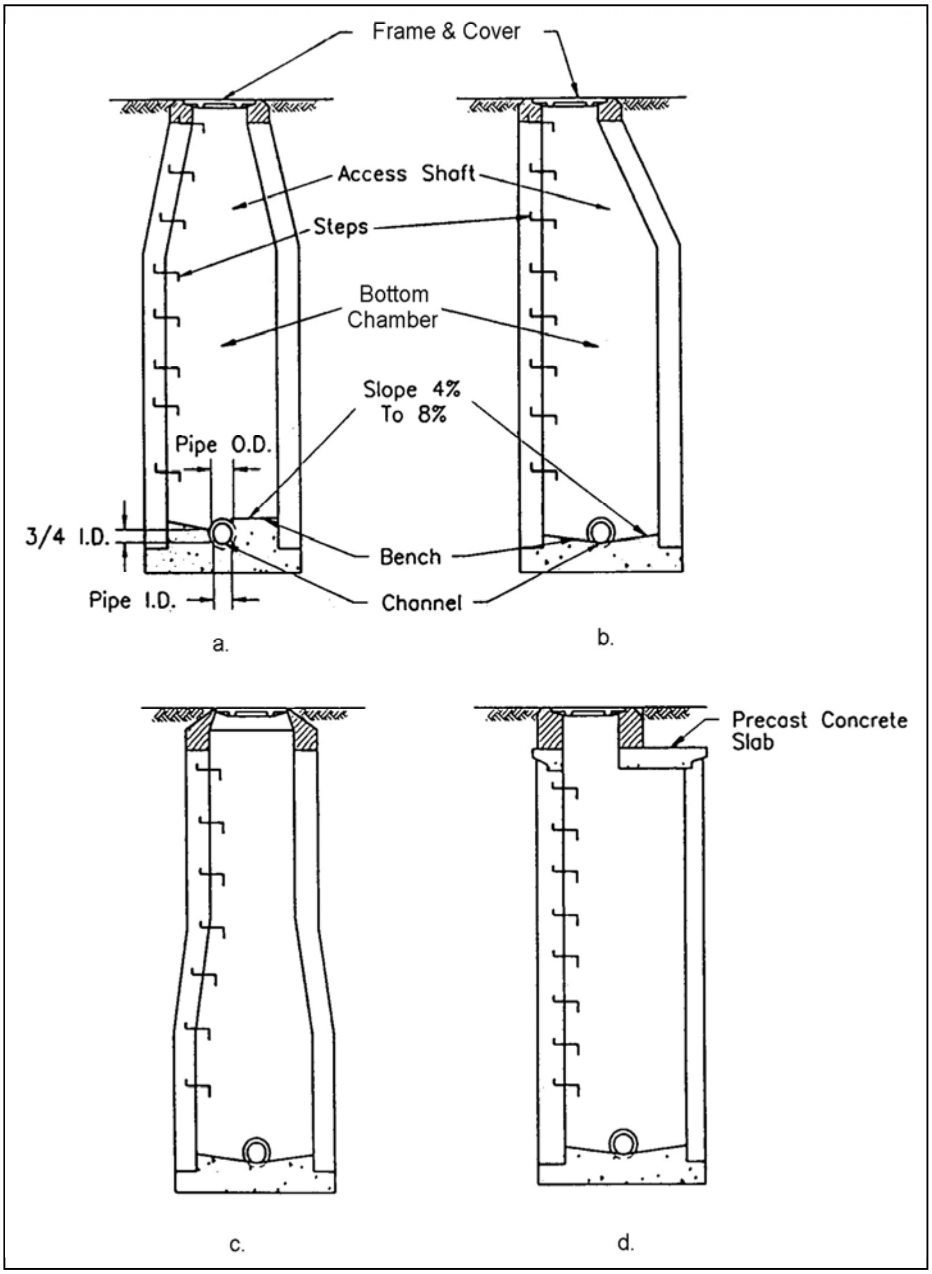
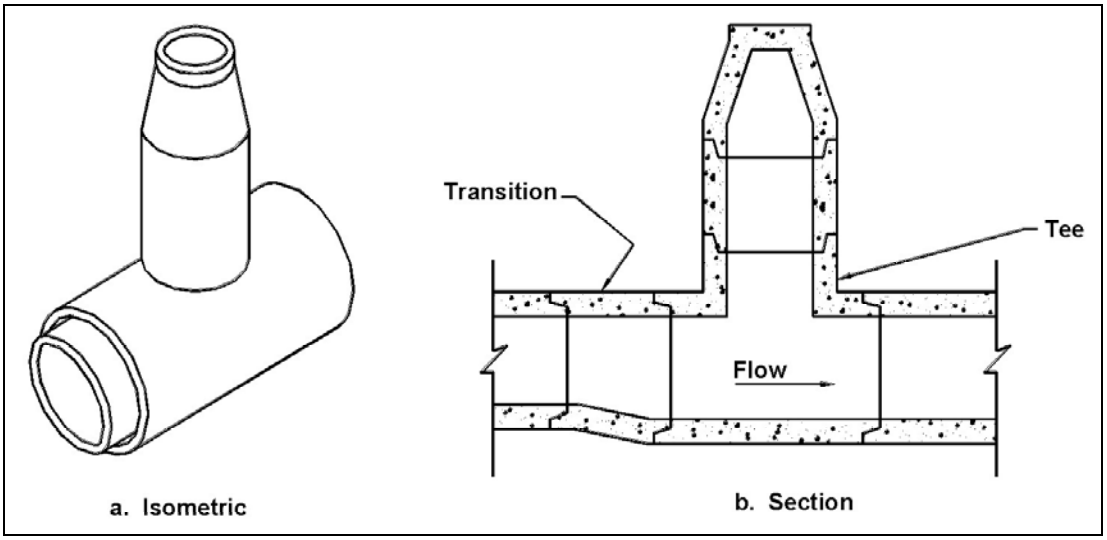


Figure 7-8. "Tee" Manhole for Large Storm Drains



If the HGL could rise above the ground surface at a manhole site, special consideration must be given to the design of the manhole frame and cover. The cover must be secured so that it remains in place during peak flooding periods, avoiding a manhole "blowout." A blowout is caused when the HGL rises in elevation higher than the manhole cover and forces the lid to explode off. Manhole covers should be bolted or secured in place with a locking mechanism if blowout conditions are possible.

7-3.4 **Channels and Benches.** Flow channels and benches are illustrated in Figure 7-7. The purpose of the flow channel is to provide a smooth, continuous conduit for the flow and to eliminate unnecessary turbulence in the manhole by reducing energy losses. The elevated bottom of the manhole on either side of the flow channel is called the bench. The purpose of a bench is to increase the hydraulic efficiency of the manhole.

In the design of manholes, benched bottoms are not common. Benching is used only when the HGL is relatively flat and there is no appreciable head available. Typically, the slopes of storm drain systems do not require benches to hold the HGL in the correct place. Where the HGL is not of consequence, avoid the extra expense of adding benches.

For the design of the inflow and outflow pipe invert elevations, the pipes should be set so the top of the outlet pipe is below the top of the inlet pipe by the amount of loss in the manhole. This practice is often referred to as "hanging the pipe on the hydraulic grade line."

7-3.5 **Manhole Depth.** The depth required for a manhole will be dictated by the storm drain profile and surface topography. Common manhole depths range from 5 to

13 ft. Manholes that are shallower or deeper than this may require special consideration.

Irregular surface topography sometimes results in shallow manholes. If the depth to the invert is only 2 to 3 ft, all maintenance operations can be conducted from the surface; however, maintenance activities are not comfortable from the surface, even at shallow depths. It is recommended that the manhole width be of the same size as that for greater depths. Typical manhole widths are 4 to 5 ft. For shallow manholes, use of an extra large cover with a 30- or 36-in. opening will enable a worker to stand in the manhole for maintenance operations.

Deep manholes must be carefully designed to withstand soil pressure loads. If the manhole is to extend very far below the water table, it must also be designed to withstand the associated hydrostatic pressure or excessive seepage may occur. Since long portable ladders would be cumbersome and dangerous, access must be provided with either steps or built-in ladders.

7-3.6 **Location and Spacing.** Manhole location and spacing criteria have been developed in response to storm drain maintenance requirements. Spacing criteria are typically established based on a local agency's past experience and maintenance equipment limitations. At a minimum, manholes should be located at specific points:

- Where two or more storm drains converge
- Where pipe sizes change
- Where a change in alignment occurs
- Where a change in grade occurs

In addition, manholes may be located at intermediate points along straight runs of storm drain in accordance with the criteria outlined in Table 7-1; however, individual transportation agencies may have limitations on spacing of manholes due to maintenance constraints.

Table 7-1. Manhole Spacing Criteria

Pipe Size, in.	Suggested Maximum Spacing, ft
12 – 24	300
27 – 36	400
42 – 54	500
60 and up	1000

7-3.7 **Settlement of Manholes**. Failure of joints between sections of concrete pipe in the vicinity of large concrete manholes indicates that the manhole has settled at a different rate than that of the connecting pipe. Flexible joints should be required for all joints between sections of rigid pipe in the vicinity of large manholes, e.g., 3 to 5 joints along all pipe entering or leaving the manhole.

7-4 **JUNCTION CHAMBERS.** A junction chamber is a specially designed underground chamber used to join two or more large storm drain conduits. This type of structure is usually required where storm drains are larger than the size that can be accommodated by standard manholes. For smaller diameter storm drains, manholes are typically used instead of junction chambers. Junction chambers by definition do not need to extend to the ground surface and can be completely buried; however, it is recommended that riser structures be used to provide for surface access and/or to intercept surface runoff.

Materials commonly used for junction chamber construction include pre-cast concrete and cast-in-place concrete. On storm drains constructed of corrugated steel, the junction chambers are sometimes made of the same material.

To minimize flow turbulence in junction boxes, flow channels and benches are typically built into the bottom of the chambers. Figure 7-9 illustrates several efficient junction channel and bench geometries. Where junction chambers are used as access points for the storm drain system, their location should adhere to the spacing criteria outlined in section 7-3.6.

7-5 MISCELLANEOUS STRUCTURES

7-5.1 **Chutes**. A chute is a steep, open channel that provides a method of discharging accumulated surface runoff over fills and embankments. A typical design is shown in Figure 7-10.

7-5.2 **Security Fencing**. When a conduit or channel passes through or beneath a security fence and forms an opening greater than 96 square inches (in^2) in area, a security barrier must be installed. Barriers are usually of bars, grillwork, or chain-link screens. Parallel bars used to prevent access will be spaced not more than 6 in. apart and will be of sufficient strength to preclude bending by hand after assembly.

7-5.2.1 Where fences enclose maximum security areas such as exclusion and restricted areas, drainage channels, ditches, and equalizers will, wherever possible, be carried under the fence in one or more pipes having an internal diameter of not more than 10 in. Where the volume of flow is such that the multipipe arrangement is not feasible, the conduit or culvert will be protected by a security grill composed of 0.75-in. diameter rods or 0.50-in. bars spaced not more than 6 in. on center, set and welded in an internal frame. Where rods or bars exceed 18 in. in length, suitable spacer bars will be provided at not more than 18 in. on center, welded at all intersections. Security grills will be located inside the protected area. Where the grill is on the downstream end of the culvert, the grill will be hinged to facilitate cleaning and provided with a latch and padlock, and a debris catcher will be installed in the upstream end of the conduit or culvert. Elsewhere the grill will be permanently attached to the culvert.

Security regulations normally require the guard to inspect such grills at least once every shift. For culverts in rough terrain, steps will be provided to the grill to facilitate inspection and cleaning.

Figure 7-9. Efficient Channel and Bench Configurations

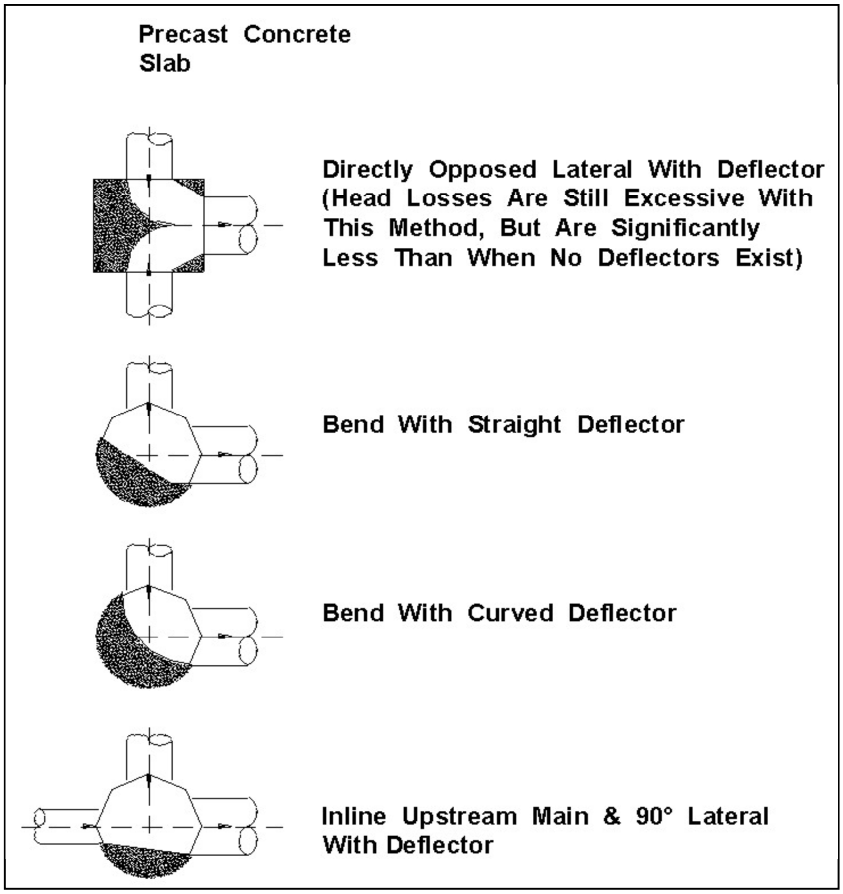
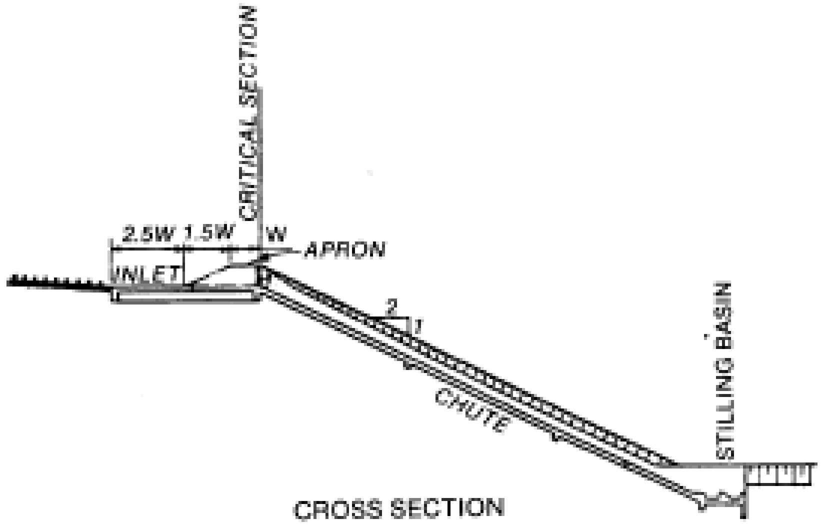
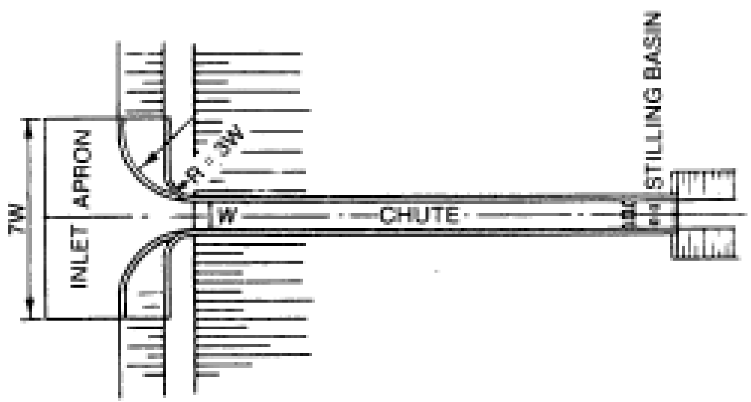


Figure 7-10. Details of a Typical Drainage Chute



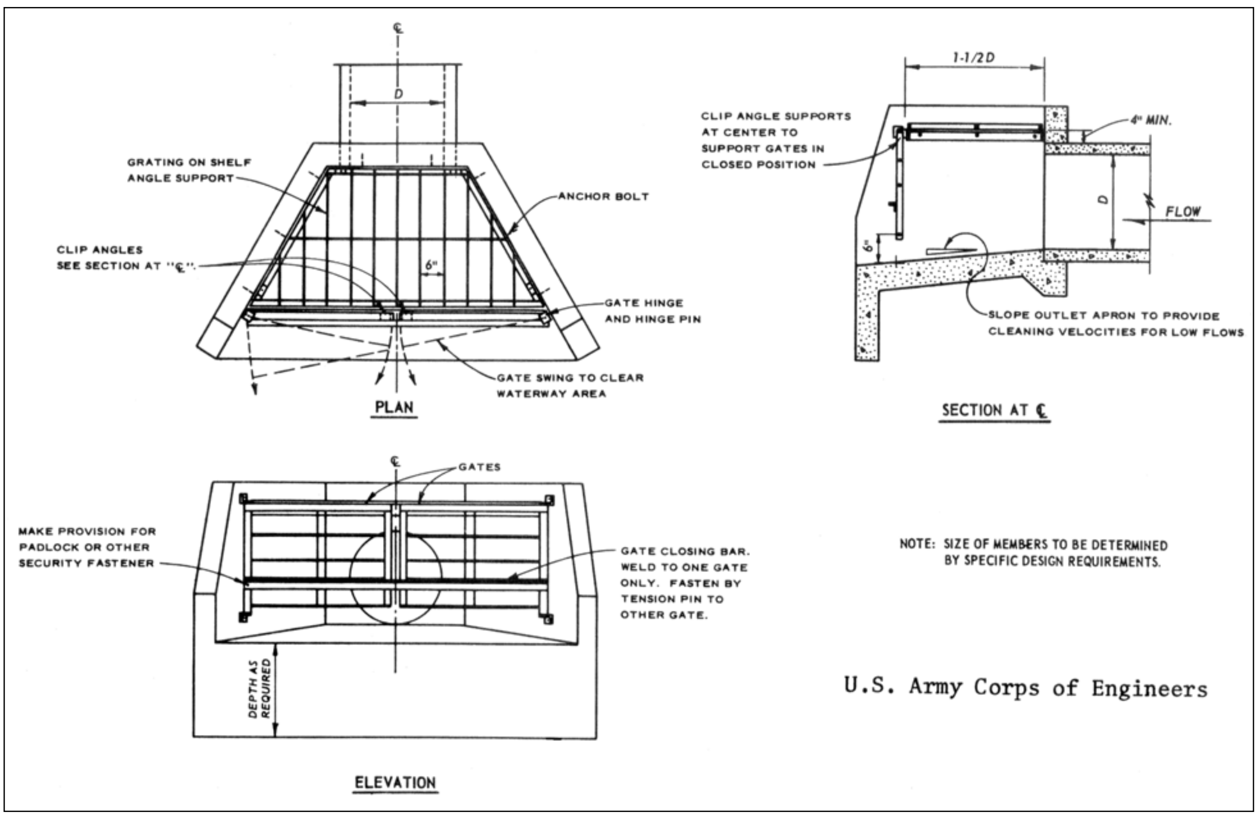


7-5.2.2 For culverts and storm drains, barriers at the intakes would be preferable to barriers at the outlets because of the relative ease of debris removal; however, barriers at the outfalls are usually essential. In these cases, consideration should be given to placing debris interceptors at the inlets. Bars constituting a barrier should be placed in a horizontal position, and the number of vertical members should be limited to minimize clogging; the total clear area should be at least twice the area of the conduit or larger under severe debris conditions. For large conduits, an elaborate cage-like structure may be required. Provisions to facilitate cleaning during or immediately after heavy runoff should be made. Figure 7-11 shows a typical barrier for the outlet of a pipe drain. Note that a 6-in. underclearance is provided to permit passage of normal bedload material, and that the apron between the conduit outlet and the barrier is placed on a slope to minimize deposition of sediment on the apron during ordinary flow. Erosion protection, where required, is placed immediately downstream from the barrier.

7-5.2.3 If manholes must be located in the immediate vicinity of a security fence, their covers must be fastened to prevent unauthorized opening.

7-5.2.4 Open channels may present special problems due to the relatively large size of the waterway and the possible requirements for passage of large floating debris. For such channels, a barrier should be provided that can be unfastened and opened or lifted during periods of heavy runoff or when clogged. The barrier is hinged at the top and an empty tank is welded to it at the bottom to serve as a float. Open channels or swales that drain relatively small areas and with flows that carry only minor quantities of debris may be secured merely by extending the fence down to a concrete sill set into the sides and across the bottom of the channel.

Figure 7-11. Outlet Security Barrier



7-5.3 **Fuel/Water Separators**. Fuel/water separators should be installed where there is an oil/water separation problem. The most common location for these units is in areas that contain vehicle washracks. Details on the selection and design of oil/water separators can be found in Army Engineering Technical Letter (ETL) 1110-3-466.

7-5.4 **Outlet Energy Dissipators.** Most drainage systems are designed to operate under normal free outfall conditions. Tailwater conditions are generally absent; however, it is possible for a discharge resulting from a drainage system to possess kinetic energy in excess of that which normally occurs in waterways. To reduce the kinetic energy and thereby reduce downstream scour, outfalls may sometimes be required to reduce streambed scour. Scour may occur in the streambed if discharge velocities exceed the critical velocities of the streambed material. Studies of local materials must be made prior to a decision to install energy dissipation devices. Protection against scour may be provided by plain outlets, transitions, and stilling basins. Plain outlets provide no protective works and depend on natural material to resist erosion. Transitions provide little or no dissipation of energy themselves, but by spreading the effluent jet to approximately the flow cross-section of the natural channel, the energy is greatly reduced prior to releasing the effluent into the outlet channel. Stilling basins dissipate the high kinetic energy of flow by a hydraulic jump or other means. Riprap may be required at any of the three types of outfalls.

7-5.4.1 **Plain Type**

- If the discharge channel is in rock or a material highly resistant to erosion, no special erosion protection is required; however, since flow from the culvert will spread with a resultant drop in water surface and increase in velocity, this type of outlet should be used without riprap only if the material in the outlet channel can withstand velocities approximately 1.5 times the velocity in the culvert. At such an outlet, side erosion due to eddy action or turbulence is more likely to prove troublesome than is bottom scour.

- Cantilevered culvert outlets may be used to discharge a free-falling jet onto the bed of the outlet channel. A plunge pool will be developed, the depth and size of which will depend on the energy of the falling jet at the tailwater and the erodibility of the bed material.

7-5.4.2 **Transition Type.** Endwalls (outfall headwalls) serve the dual purpose of retaining the embankment and limiting the outlet transition boundary. Erosion of embankment toes usually can be traced to eddy attack at the ends of such walls. A flared transition is very effective if proportioned so that eddies induced by the effluent jet do not continue beyond the end of the wall or overtop a sloped wall. A guideline is that the product of velocity and flare angle should not exceed 150. That is, if effluent velocity is 5 ft/s, each wingwall may flare 30 degrees; but if velocity is 15 ft/s, the flare should not exceed 10 degrees. Unless wingwalls can be anchored on a stable foundation, a paved apron between the wingwalls is required. Take special care in design of the structure to preclude undermining. A newly excavated channel may be expected to degrade, and proper allowance for this action should be included in establishing the apron elevation and the depth of the cutoff wall. Warped endwalls provide excellent transitions because they result in the release of flow in a trapezoidal section, which generally approximates the cross section of the outlet channel. If a warped transition is placed at the end of a curved section below a culvert, the transition is made at the end of the curved section to minimize the possibility of overtopping due to superelevation of the water surface. A paved apron is required with warped endwalls. Usually riprap is required at the end of a transition-type outlet.

7-5.4.3 **Improved Channels**. Improved channels, especially the paved ones, commonly carry water at velocities higher than those prevailing in the natural channels into which they discharge. Often riprap will suffice for dissipation of excess energy. A cutoff wall may be required at the end of a paved channel to preclude undermining. In extreme cases, a flared transition, stilling basin, or impact device may be required.

7-5.5 **Drop Structures and Check Dams.** Drop structures and check dams are designed to check channel erosion by controlling the effective gradient and to provide for abrupt changes in channel gradient by means of a vertical drop. These structures also provide satisfactory means for discharging accumulated surface runoff over fills with heights not exceeding approximately 5 ft and over embankments higher than 5 ft, provided the end sill of the drop structure extends beyond the toe of the embankment. The check dam is a modification of the drop structure used for erosion control in small channels where a less elaborate structure is permissible.

7-5.6 **Transitions.** In storm drainage systems, transitions from one pipe size to another typically occur in manholes or junction chambers; however, there are times when transitions may be required at other locations within the storm drainage system. A typical example is illustrated in Figure 7-12, where a rectangular pipe transition is used to avoid an obstruction. Commercially available transition sections are also available for circular pipes. These transitions can be used upstream of "tee"-type manholes in large storm drains, as illustrated in Figure 7-12. Providing a smooth, gradual transition to minimize head losses is the most significant consideration in the design of transition sections. Table 7-2 provides design criteria for transition sections.

7-5.7 **Flow Splitters.** A flow splitter is a special structure designed to divide a single flow and divert the parts into two or more downstream channels. Flow splitters are constructed similar to junction boxes except that with flow splitters, flows from a single large storm drain are split into several smaller storm drains.

The design of flow splitters must minimize head loss and potential debris problems. Hydraulic disturbances at the point of flow division result in unavoidable head losses. These losses may be reduced by the inclusion of proper flow deflectors in the design of the structure. Hydraulic disturbances within flow splitters often result in regions of flow velocity reduction. These reductions can cause deposition of material suspended in the storm water flow. In addition, the smaller pipes may not be large enough to carry some of the debris being passed by the large pipe. In some cases, flow splitters can become maintenance intensive; therefore, their use should be judiciously controlled, and when used, positive maintenance access must be provided.

Figure 7-12. Transitions to Avoid Obstruction

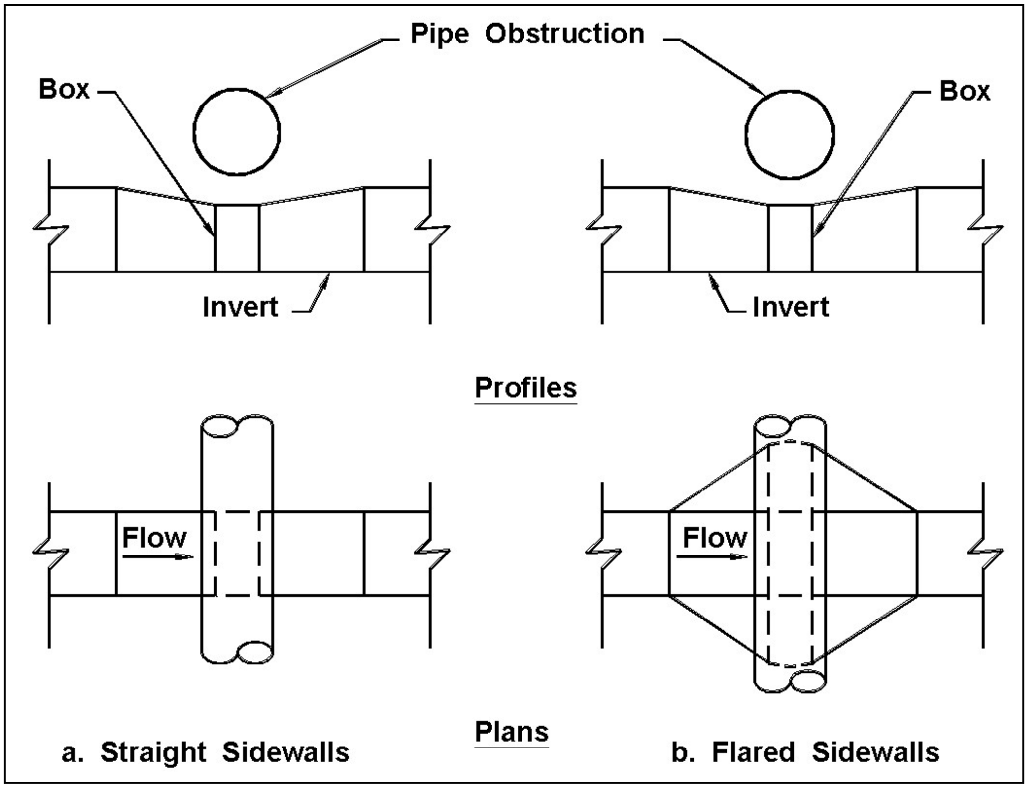
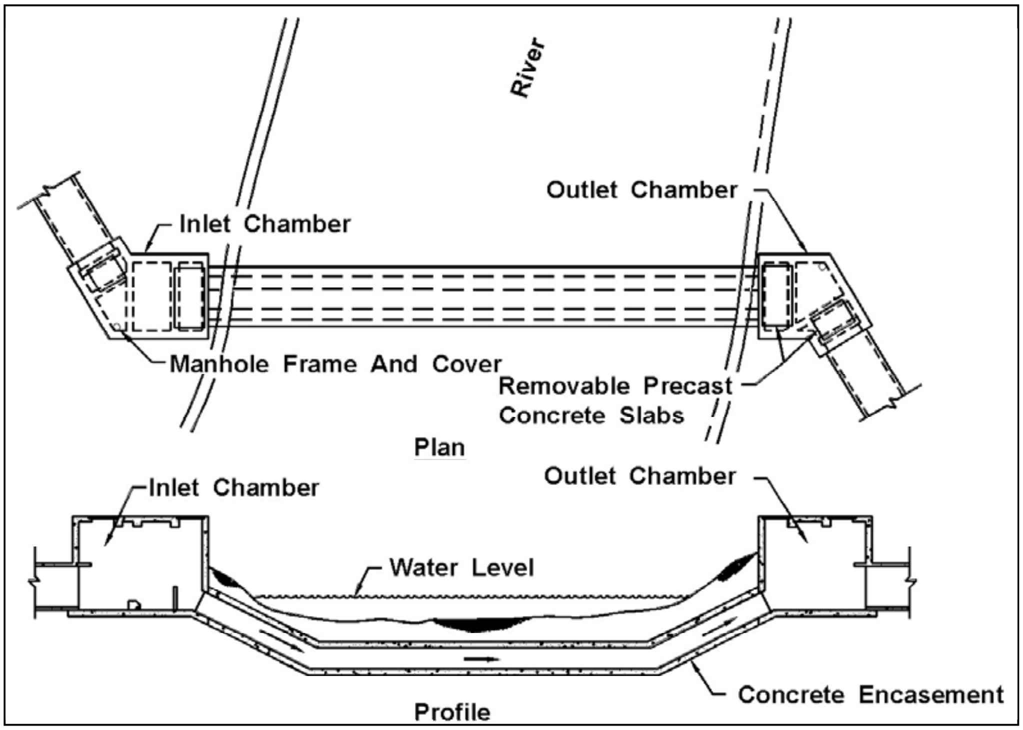


Table 7-2. Transition Design Criteria

Type	Flow Condition	
	V < 20 ft/s	*V* > 20 ft/s
Expansion	Straight Walls Ratio - 5:1 to 10:1	Straight Walls Ratio - 10:1 to 20:1
Contraction	Straight Walls Ratio - 5:1 to 10:1	Straight Walls Ratio - 10:1 to 20:1

7-5.8 **Siphons.** In practice, the term "siphon" refers to an inverted siphon or depressed pipe that would stand full even without any flow. Its purpose is to carry the flow under an obstruction such as a stream or depressed highway and to regain as much elevation as possible after the obstruction has been passed. Siphons can consist of single or multiple barrels; however, AASHTO recommends a minimum of two barrels. Figure 7-13 illustrates a twin-barrel siphon.

Figure 7-13. Twin-Barrel Siphon



Certain considerations are important to the efficient design of siphons:

- Self flushing velocities should be provided under a wide range of flows.
- Hydraulic losses should be minimized.
- Provisions for cleaning should be provided.
- Sharp bends should be avoided.
- The rising portion of the siphon should not be steep enough to make it difficult to flush deposits. (Some agencies limit the rising slope to 15 percent.)
- There should be no change in pipe diameter along the length of the siphon.
- Provisions for drainage should be considered.

7-5.9 **Flap Gates.** Flap gates are installed at or near storm drain outlets for the purpose of preventing back-flooding of the drainage system at high tides or high stages in the receiving streams. A small differential pressure on the back of the gate will open it, allowing discharge in the desired direction. When water on the front side of the gate rises above that on the back side, the gate closes to prevent backflow. Flap gates are typically made of cast iron, rubber, or steel, and are available for round, square, and rectangular openings and in various designs and sizes.

Maintenance is a necessary consideration with the use of flap gates. In storm drain systems that are known to carry significant volumes of suspended sediment and/or floating debris, flapgates can act as skimmers and cause brush and trash to collect between the flap and seat. The reduction of flow velocity behind a flap gate may also cause sediment deposition in the storm drain near the outlet. Flap gate installations require regular inspection and removal of accumulated sediment and debris.

In addition, for those drainage structures that have a flap gate mounted on a pipe projecting into a stream, the gate must be protected from damage by floating logs or ice during high flows. In these instances, protection must be provided on the upstream side of the gate.

7-6 DESIGN FEATURES

7-6.1 **Grates.** Grating elevations for area inlets must be carefully coordinated with the base or airport grading plan. Each inlet must be located at an elevation that will ensure interception of surface runoff. Increased overland velocities immediately adjacent to field inlet openings may result in erosion unless protective measures are taken. A solid sod annular ring varying from 3 to 10 ft around the inlet reduces erosion if suitable turf is established and maintained on the adjacent drainage area. Prior to the establishment of turf on the adjacent area, silt may deposit in a paved apron around the perimeter or deposit in the sod ring, thereby diverting flow from the inlet. In lieu of a sod ring, a paved apron around the perimeter of a grated inlet may be beneficial in preventing erosion and differential settlement of the inlet and the adjacent area as well as facilitating mowing operations.

7-6.1.1 Drainage structures in non-paved areas should be designed so that the grating does not extend above the ground level. The tops of such structures should permit unobstructed use of the area by equipment and facilitate collection of surface runoff.

7-6.1.2 An area inlet in a ponded area operates as a weir under low head situations. At higher heads, however, the grating acts as an orifice. A complete description of grates acting under weir and orifice flow is provided in Chapter 3.

7-6.1.3 Typically a grated inlet in a sloping gutter will intercept all the flow approaching the gross width of the grate opening. The size and spacing of the bars of grated inlets are influenced by the traffic and safety requirements of the local area; nevertheless, in the interest of hydraulic capacity and maintenance requirements, it is desirable that the openings be made as large as traffic and safety requirements will permit. To prevent possible clogging by debris, safety factors are required and are addressed in Chapter 3.

7-6.1.4 Grates may be made of cast iron, steel, or ductile iron; however, cast iron grates may not be used in areas where grates may be subjected to wheel loads. Reinforced concrete grates, with circular openings, may be designed for box drains. Inlet grating and frames must be designed to withstand aircraft wheel loads of the largest aircraft using or expected to use the facility. As design loads vary, the grates should be carefully checked for load-carrying capacities. Selection of grates and frames will depend upon capacity, strength, anchoring, or the requirement for single or multiple grates. The suggested design of typical metal grates and inlets is shown in Figures 7-14 and 7-15.

7-6.1.5 Commercially manufactured grates and frames for airport loadings have been designed specifically for airport loadings from 50 to 250 lb/in^2. Hold-down devices have also been designed and are manufactured to prevent grate displacement by aircraft traffic. If manufactured grates are used, the vendor must certify the design load capacity. All grates to be used under loaded conditions should be delivered without paintings or coatings to allow for inspection of cracks and other imperfections prior to installation.

7-6.1.6 For rigid concrete pavements, grates may be protected by expansion joints around the inlet frames. Construction joints, which match or are equal to the normal spacing of joints, may be required around the drainage structure. The slab around the drainage structure should include steel reinforcements to control cracking outwardly from each corner of the inlet.

7-6.2 **Ladders**. Adequate ladders should be provided to assure that rapid entrance and egress may be made by personnel during an inspection of facilities. Ladder rungs should be checked periodically since they are often lost in the course of regular inspection and maintenance work. Fixed ladders will be provided depending on the depth of the structures. DOD projects require ladders on all structures over 12 ft in depth. Access to manhole and junction boxes without fixed ladders will be by portable ladders.

Figure 7-14. Examples of Typical Inlet Grates

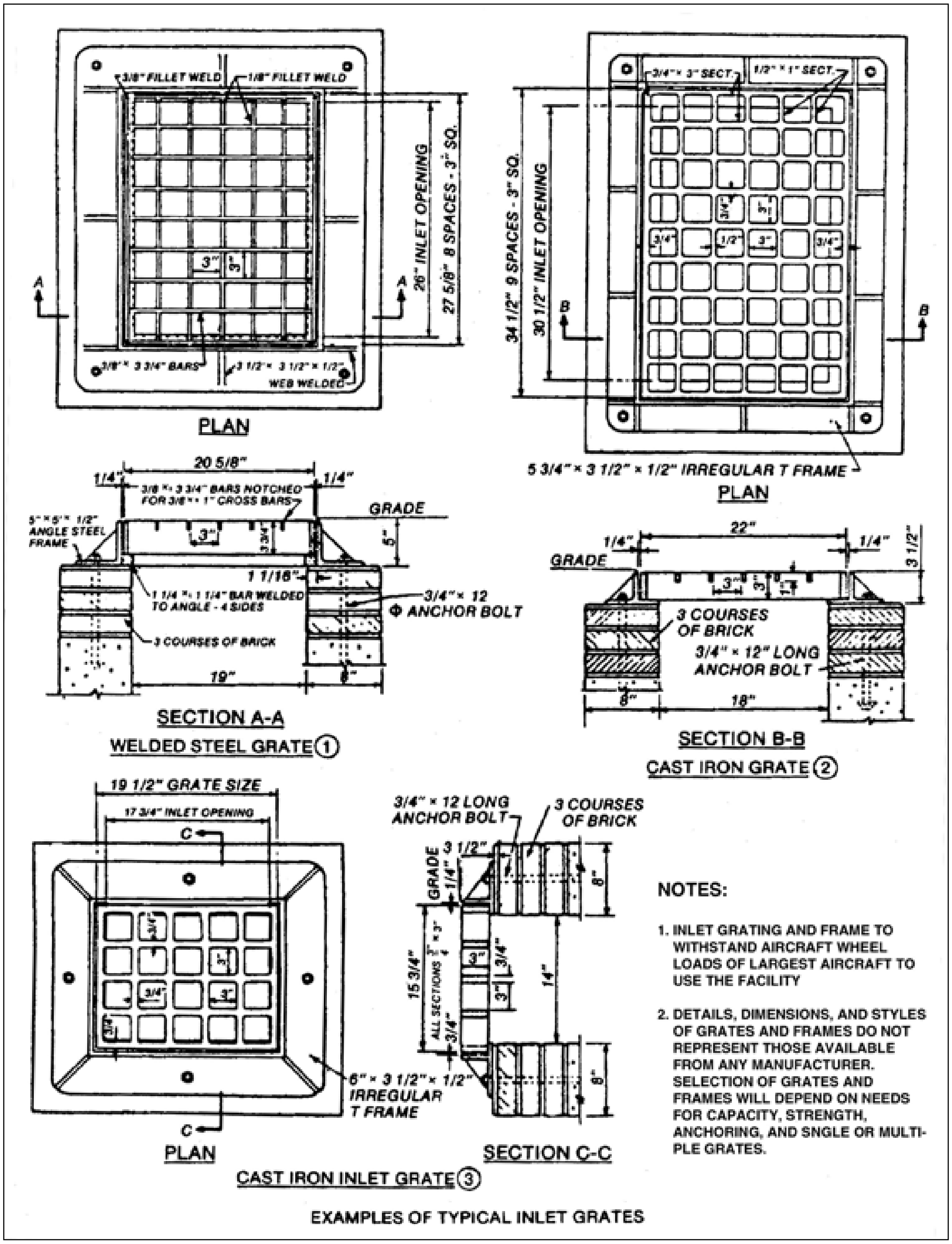
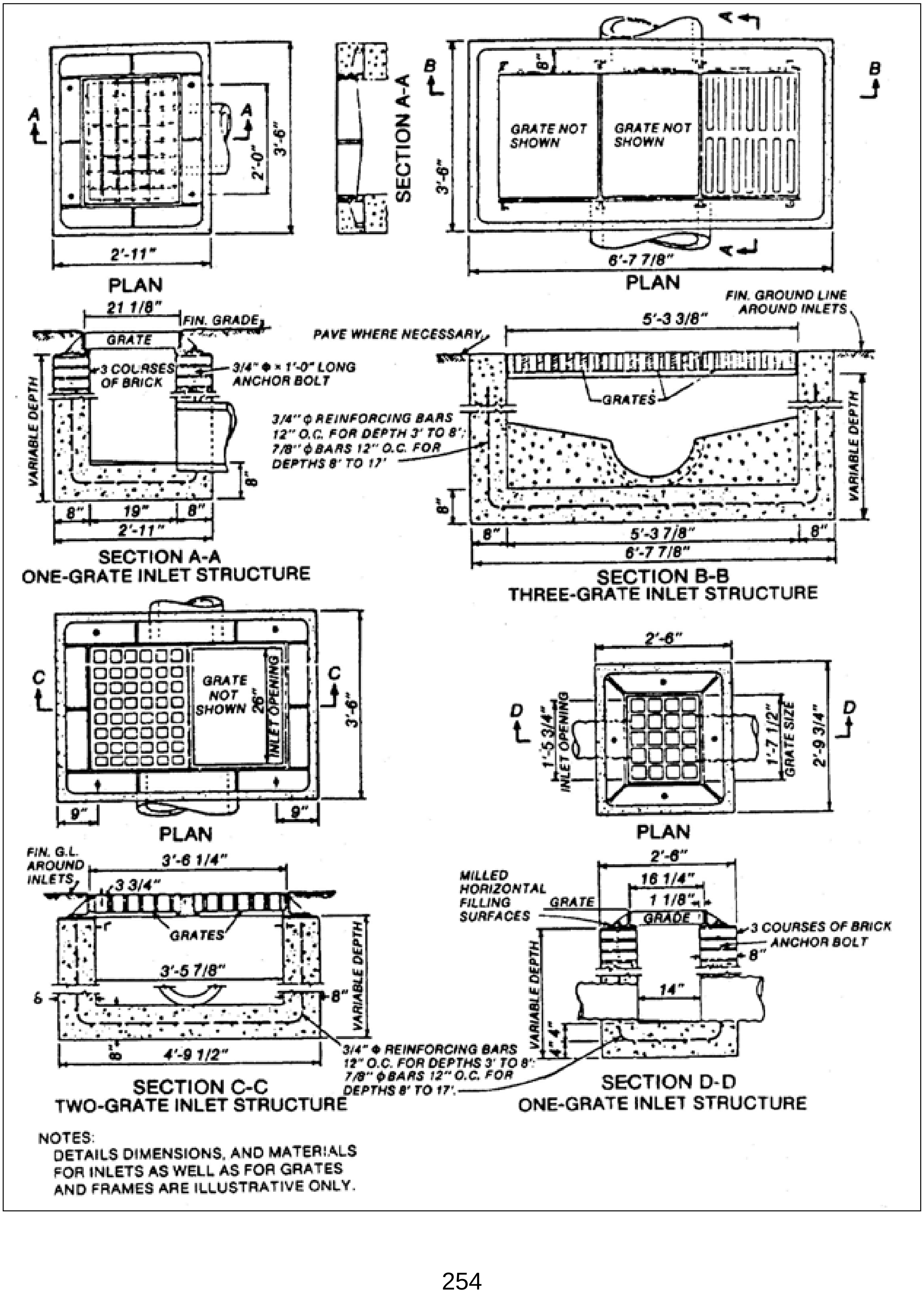


Figure 7-15. Examples of Inlet Design



7-6.3 **Steps.** Steps are intended to provide a means of convenient access to manholes. Where access steps are provided, each step should be designed to comply with Occupational Safety and Health Administration (OSHA) requirements. The steps should be corrosion resistant. Steps coated with neoprene or epoxy or steps fabricated from rust-resistant material such as stainless steel or aluminum coated with bituminous paint are preferable. Steps made from reinforcing steel are absolutely unacceptable.

Note that some agencies have abandoned the use of manhole steps in favor of having maintenance personnel supply their own ladders. Reasons for this include danger from rust-damaged steps and the desire to restrict access. In addition, DOD does not recommend the use of steps on any structure.

7-7 SPECIAL DESIGN CONSIDERATIONS FOR AIRFIELDS

7-7.1 **Overview**. Structures built in connection with airport drainage are similar to those used in conventional construction, but these structures must be capable of supporting the heaviest design aircraft wheel load. Although standard-type structures are usually adequate for roads, special structures will be needed occasionally.

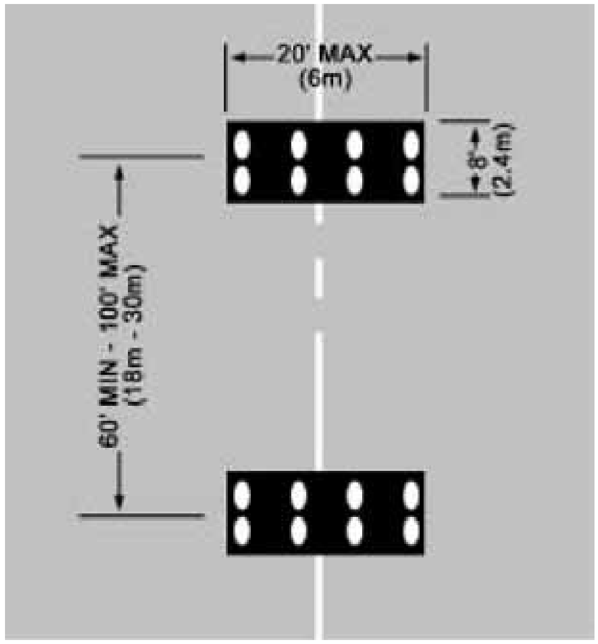
Future heavy aircraft may increase point loadings on some structures (e.g., manhole covers), while on other structures the entire aircraft weight may be imposed on a deck span, pier, or footing (e.g., overpasses). Strengthening of drainage structures after the initial construction may prove extremely difficult, costly, and time consuming.

7-7.2 Recommended Design Parameters

7-7.2.1 **Structural Considerations.** For many drainage structures, the design load is highly dependent upon the aircraft gear configuration. While the exact gear configuration of future heavy aircraft is unknown, three basic gear configurations will be used to design for future heavy loads: Type A – Bicycle; Type B – Tricycle; and Type C – Tricycle. The three basic gear configurations for future heavy aircraft come from FAA AC 150/5320-6D*.* For a given aircraft gross weight, each of the three basic gear configurations will be used in the design of each drainage component. Then, for each drainage component, the basic gear configuration that results in the most conservative design will be selected as the design gear configuration for that component. For purposes of design, each of the three basic configurations contains two wheel groups of eight wheels each (sixteen wheels per aircraft). Each wheel group occupies an area of 20 ft by either 6 ft or 8 ft, with each wheel group supporting one-half of the aircraft gross weight. Wheel prints are uniformly spaced within each of the respective wheel groups. Nose gears are not considered in the design, except as they occur in the static load.

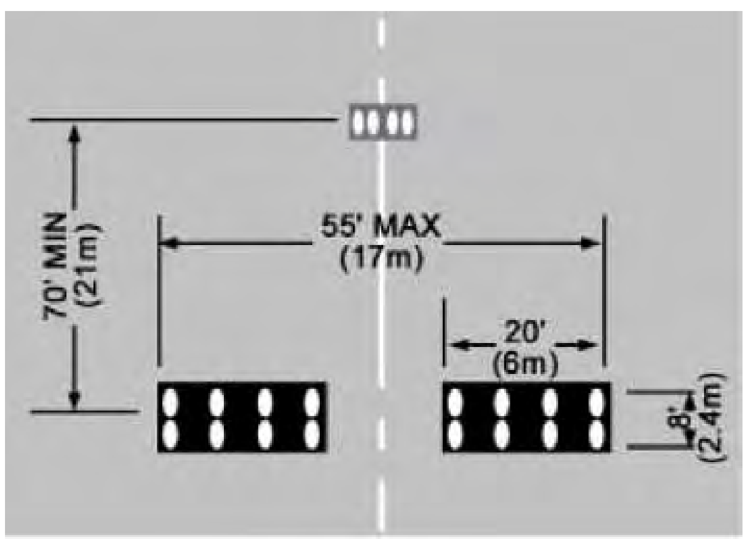
7-7.2.1.1 **Type A – Bicycle.** The Type A – Bicycle configuration (Figure 7-16) consists of two wheel groups located along a single line parallel to the primary aircraft axis (i.e., parallel to the line of travel), but with the major axis of each wheel group oriented perpendicular to the primary aircraft axis.

Figure 7-16. Type A – Bicycle Gear Configuration



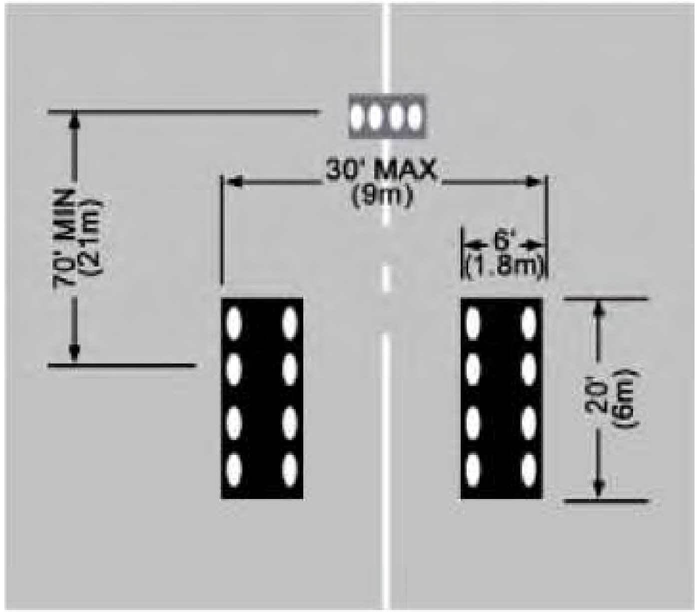
7-7.2.1.2 **Type B – Tricycle.** The Type B – Tricycle configuration (Figure 7-17) includes a nose gear and has wheel groups whose major axes are coincident and perpendicular to the major aircraft axis.

Figure 7-17. Type B – Tricycle Gear Configuration



7-7.2.1.3 **Type C – Tricycle.** The Type C – Tricycle configuration (Figure 7-18) includes a nose gear and has wheel groups whose major axes are parallel to, and equidistant from, the principal aircraft axis.

Figure 7-18. Type C – Tricycle Gear Configuration



7-7.2.2 **Loads.** All loads discussed in this UFC are to be considered as dead load (DL) plus live loads (LL). The design of structures subject to direct wheel loads should also anticipate braking loads as high as 0.7 g (for no-slip brakes).

7-7.2.3 **Direct Loading.** Decks and covers subject to direct heavy aircraft loading, such as manhole covers, inlet grates, utility tunnel roofs, and bridges, should be designed for these loadings:

7-7.2.3.1 Manhole covers for 100-kip wheel loads with tire pressure of 250 lb/in^2.

7-7.2.3.2 For spans of 2 ft or less in the least direction, apply a uniform live load of 250 lb/in^2.

7-7.2.3.3 For spans greater than 2 ft in the least direction, the design will be based on the number of wheels that will fit the span. Wheel loads of 50 to 75 kip should be considered.

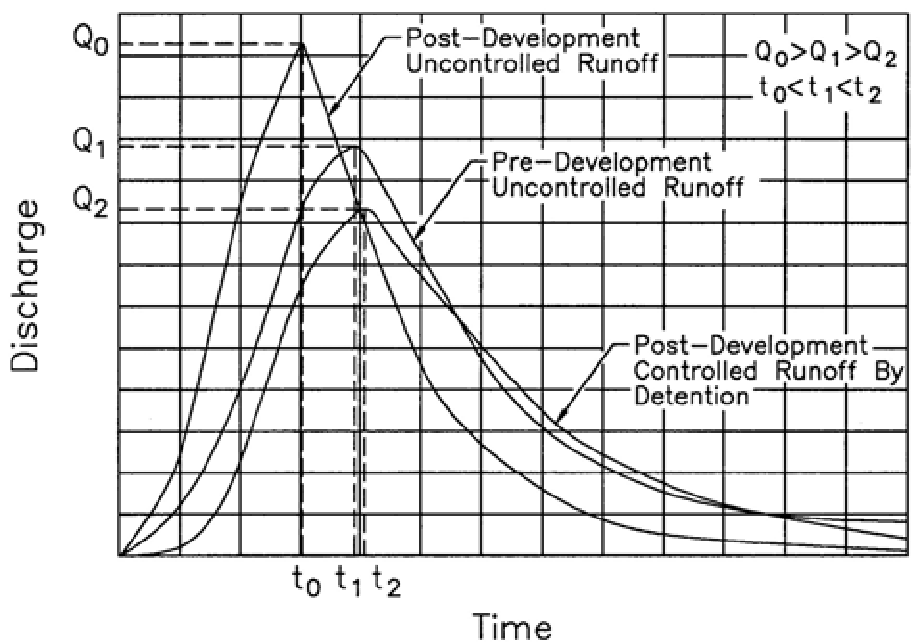
7-7.2.3.4 For structures that will be required to support both in-line and directional traffic lanes such as diagonal taxiways or apron taxi routes, load transfer at expansion joints will not be considered in the design process; however, if specific knowledge about the long-term load transfer characteristics of a particular feature supports the use of load transfer in the design of a particular drainage structure, then an exception is allowed and load transfer will be considered.

CHAPTER 8

STORM WATER CONTROL FACILITIES

8-1 **GENERAL.** Many land development activities, including the construction of roads and airports, convert natural pervious areas to impervious areas. These activities cause increased runoff because infiltration is reduced, the surface is usually smoother, allowing more rapid drainage, and depression storage is usually reduced. In addition, natural drainage systems are often replaced by lined channels, storm drains, and curb-and-gutter systems. These man-made systems produce an increase in runoff volume and peak discharge as well as a reduction in the time to peak of the runoff hydrograph. This concept is illustrated by the hydrograph in Figure 8-1.

Figure 8-1. Hydrograph Schematic



8-1.1 **Storage and Detention/Retention Benefits**. The temporary storage or detention/retention of excess storm water runoff as a means of controlling the quantity and quality of storm water releases is a fundamental principle in storm water management and a necessary element of many storm drainage systems. Previous concepts that called for the rapid removal of storm water runoff from developed areas, usually by downstream channelization, are now being combined with methods for storing storm water runoff to prevent overloading of existing downstream drainage systems. The storage of storm water can reduce the frequency and extent of downstream flooding, soil erosion, sedimentation, and water pollution. Detention/retention facilities also have been used to reduce the costs of large storm drainage systems by reducing the required size for downstream storm drain conveyance systems. The use of detention/retention facilities can reduce the peak discharge from a given watershed, as shown in Figure 8-1. The reduced post-development runoff hydrograph is typically designed so that the peak flow is equal to or less than the pre-developed runoff peak flow rate. Additionally, the volume of the post-development hydrograph is the same as the volume of the reduced post-development runoff hydrograph. Specific design criteria, detailed design guidance, and example problems that address storm water management are provided in Chapter 8 of HEC-22.

8-1.2 **Design Objectives**

8-1.2.1 One of the fundamental objectives of storm water management is to maintain the peak runoff rate from a developing area at or below the pre-development rate to control flooding, soil erosion, sedimentation, and pollution. Design criteria related to pollution control are presented in Chapter 11.

8-1.2.2 Specific design criteria for peak flow attenuation are typically established by local government bodies. Some jurisdictions also require that flow volume be controlled to pre-development levels as well. Controlling flow volume is only practical when site conditions permit infiltration. To compensate for the increase in flow volume, some jurisdictions require that the peak post-development flow be reduced to below pre-development levels.

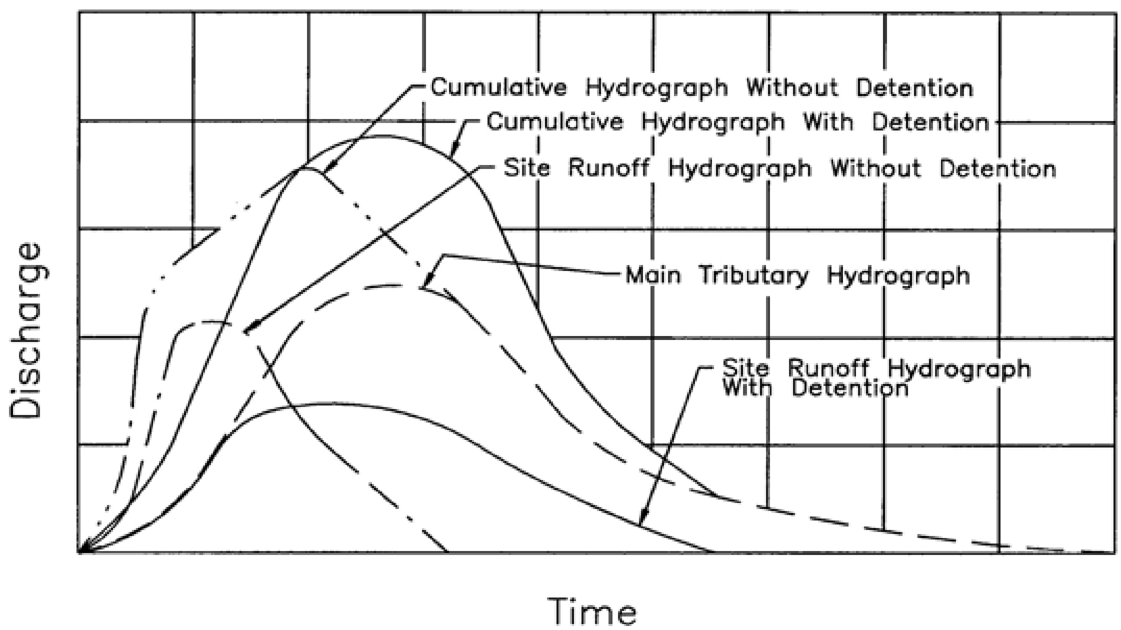
8-1.2.3 When storm water management first became common, most detention/ retention facilities were designed for control of runoff from only a single storm frequency. Typically, 2-year, 10-year, or 100-year storms were selected as the controlling criteria. However, single storm criteria have been found rather ineffective since such a design may provide little control of other storms. For example, design for the control of frequent storms (low return periods) provides little attenuation of less frequent but much larger storm events. Similarly, design for less frequent large storms provides little attenuation for the more frequent smaller storms. Some jurisdictions now enforce multiple-storm regulatory criteria that dictate that multiple storm frequencies be attenuated in a single design. A common criteria would be to regulate the 2-year, 10-year, and 100-year events.

8-2 **ISSUES RELATED TO STORM WATER QUANTITY CONTROL FACILITIES.** Three potential problem areas are associated with the design of storm water quantity control facilities, and these problem areas must be considered during design. They are release timing, safety, and maintenance.

8-2.1 **Release Timing**. The timing of releases from storm water control facilities can be critical to the proper functioning of overall storm water systems. As illustrated in Figure 8-1, storm water quantity control structures reduce the peak discharge and increase the duration of flow events. Though this is the desired result for flow tributary to an individual storm water control facility, this shifting of flow peak times and durations in some instances can cause adverse effects downstream.

For example, where the drainage area being controlled is in a downstream portion of a larger watershed, delaying the peak and extending the recession limb of the hydrograph may result in a higher peak on the main channel. As illustrated in Figure 8-2, this can occur if the reduced peak on the controlled tributary watershed is delayed in such a way that it reaches the main stream at or near the time of its peak. On occasions, it has also been observed that in locations where multiple detention facilities have been installed within developing watersheds, downstream storm flooding problems continue to be noticed. In both of these cases, the natural timing characteristics of the watershed are not being considered, and are not being duplicated by the uncoordinated use of randomly located detention facilities. It is critical that release timing be considered in the analysis of storm water control facilities to ensure the desired result.

Figure 8-2. Example of a Cumulative Hydrograph with and without Detention



8-2.2 **Safety**

8-2.2.1 In the design of water quantity control facilities, it is important to consider the possibility that people may be attracted to the site, regardless of whether or not the site or structure is intended for their use. It is important to design and construct inflow and outflow structures with safety in mind. Considerations for promoting safety include preventing public trespass, providing emergency escape aids, and eliminating other hazards.

8-2.2.2 Removable, hydraulically-efficient grates and bars may be considered for all inlet and outlet pipes, particularly if they connect with an underground storm drain system and/or they present a safety hazard. Fences may be needed to enclose ponds.

8-2.2.3 Where active recreation areas are incorporated into a detention basin, very mild bottom slopes should be used along the periphery of the storage pond. Ideally, detention basins should be located away from busy streets and intersections. Outflow structures should be designed to limit flow velocities at points where people could be drawn into the discharge stream. Persons who enter a detention pond or basin during periods when storm water is being discharged may be at risk. The force of the currents may push a person into an outflow structure or may hold a victim under the water where a bottom discharge is used. Several design precautions intended to improve safety are addressed in other storm water publications.

8-2.2.4 In the case of airfields, give special consideration to the attraction of wildlife to the facility. Waterfowl, in particular, create a significant safety hazard to aircraft and therefore must be considered during the design phase. For more information on waterfowl hazards, refer to AFPAM 91-212 or AC 150/5200-33.

8-2.3 **Maintenance.** Storm water management facilities must be properly maintained if they are to function as intended over a long period of time. Certain types of maintenance tasks should be performed periodically to ensure that storm water management facilities function properly:

- Inspections: Storm water storage facilities should be inspected periodically for the first few months after construction and on an annual basis thereafter. In addition, these facilities should be inspected during and after major storm events to ensure that the inlet and outlet structures are still functioning as designed, and that no damage or clogging has occurred.

- Mowing: Impoundments should be mowed at least twice a year to discourage woody growth and control weeds.

- Sediment, Debris and Litter Control: Accumulated sediment, debris, and litter should be removed from detention facilities at least twice a year. Particular attention should be given to removing sediment, debris, and trash around outlet structures to prevent clogging of the control device.

- Nuisance Control: Standing water or soggy conditions within the lower stage of a storage facility can create nuisance conditions such as odors, insects, and weeds. Allowance for positive drainage during design will minimize these problems. Additional control can be provided by periodic inspection and debris removal, and by ensuring that outlet structures are kept free of debris and trash.

- Structural Repairs and Replacement: Inlet and outlet devices and standpipe or riser structures have been known to deteriorate with time, and may have to be replaced. The actual life of a structural component will depend on individual, site-specific criteria, such as soil conditions.

8-3 **STORAGE FACILITY TYPES.** Storm water quantity control facilities can be classified by function as either detention or retention facilities. The primary function of detention is to store and gradually release or attenuate storm water runoff by way of a control structure or other release mechanism. True retention facilities provide for storage of storm water runoff, and release via evaporation and infiltration only. Retention facilities that provide for slow release of storm water over an extended period of several days or more are referred to as extended detention facilities.

8-3.1 **Detention Facilities**

8-3.1.1 The detention concept is most often employed in highway and municipal storm water management plans to limit the peak outflow rate to that which existed from the same watershed before development for a specific range of flood frequencies. Detention storage may be provided at one or more locations and may be both above or below ground. These locations may exist as impoundments, collection and conveyance facilities, underground tanks, and on-site facilities such as parking lots, pavements, and basins. The facility may have a permanent pool, known as a wet pond. Wet ponds are typically used where pollutant control is important. Detention ponds are the most common type of storage facility used for controlling storm water runoff peak discharges. The majority of these are dry ponds that release all the runoff temporarily detained during a storm.

8-3.1.2 Detention facilities should be provided only where they are shown to be beneficial by hydrologic, hydraulic, and cost analysis. Additionally, some detention facilities may be required by ordinances and should be constructed as deemed appropriate by the governing agency. Specific design guidance and criteria for detention storage apply:

- Design rainfall frequency, intensity, and duration must be consistent with applicable standards and local requirements.

- The facility's outlet structure must limit the maximum outflow to allowable release rates. The maximum release rate may be a function of existing or developed runoff rates, downstream channel capacity, potential flooding conditions, and/or local ordinances.

- The size, shape, and depth of a detention facility must provide sufficient volume to satisfy the project's storage requirements. This is best determined by routing the inflow hydrograph through the facility. HEC-22, Chapter 8, outlines techniques that can be used to estimate an initial storage volume, and provides an explanation of storage routing techniques.

- An auxiliary outlet must be provided to allow overflow that may result from excessive inflow or clogging of the main outlet. This outlet should be positioned such that overflows will follow a predetermined route. Preferably, such outflows should discharge into open channels, swales, or other approved storage or conveyance features.

- The system must be designed to release excess storm water expeditiously to ensure that the entire storage volume is available for subsequent storms and to minimize hazards. A dry pond, which is a facility with no permanent pool, may need a paved low flow channel to ensure complete removal of water and to aid in nuisance control.

- The facility must satisfy Federal and state statutes and recognize local ordinances. Some of these statutes are the Federal Water Pollution Control Act, the Water Quality Act, and other Federal, state, and local regulations.

- Access must be provided for maintenance.

- If the facility will be an "attractive nuisance" or is not considered reasonably safe, it may have to be fenced and/or signed.

8-3.2 **Retention Facilities**

8-3.2.1 Retention facilities as defined here include extended detention facilities, infiltration basins, and swales. In addition to storm water storage, retention may be used for water supply, recreation, pollutant removal, aesthetics, and/or groundwater recharge. As explained in Chapter 11, infiltration facilities provide significant water quality benefits, and although groundwater recharge is not a primary goal of highway storm water management, the use of infiltration basins and/or swales can provide this secondary benefit.

8-3.2.2 Retention facilities are typically designed to provide the dual functions of storm water quantity and quality control. These facilities may be provided at one or more locations and may be either above or below ground. These locations may exist as impoundments, collection and conveyance facilities (swales or perforated conduits), and on-site facilities such as parking lots and roadways using pervious pavements.

8-3.2.3 Design criteria for retention facilities are the same as those for detention facilities except that it may not be necessary to remove all runoff after each storm. Additional criteria should be applied, however. See paragraphs 8-3.3 and 8-3.4 for this criteria.

8-3.3 **Wet Pond Facilities**

- Wet pond facilities must provide sufficient depth and volume below the normal pool level for any desired multiple use activity.

- Shoreline protection should be provided where erosion from wave action is expected.

- The design should include a provision for lowering the pool elevation or draining the basin for cleaning purposes, shoreline maintenance, and emergency operations.

- Any dike or dam must be designed with a safety factor commensurate with an earth dam and/or as set forth in state statutes.

- Safety benching should be considered below the permanent water line at the toe of steep slopes to guard against accidental drowning.

8-3.4 **Infiltration Facilities**

- A pervious bottom is necessary to ensure sufficient infiltration capability to drain the basin in a reasonable amount of time so that it will have the capacity needed for another event.

- Because of the potential delay in draining the facility between events, it may be necessary to increase the emergency spillway capacity and/or the volume of impoundment.

- Detailed engineering geological studies are necessary to ensure that the infiltration facility will function as planned.

- Particulates from the inflow should be removed so they do not settle and preclude infiltration.

The FHWA’s TS-80-218 is recommended for additional information on underground detention and retention facilities.