Federal Aviation Agency

ADVISORY CIRCULAR

AC NO: AC 150/5320-5A	AIRPORTS
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SUBJECT: AIRPORT DRAINAGE

1. PURPOSE.

This circular provides guidance for airport managers, engineers, and the public in the design and maintenance of airport drainage systems.

2. CANCELLATION.

This publication cancels "Airport Drainage," dated 1960.

3. REFERENCES.

The following publications provide further guidance and technical information as may be required. They may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Send a check or money order with your request made payable to the Superintendent of Documents. No c.o.d. orders are accepted.

a. Federal Aviation Agency, AC 150/5370-1, Standard Specifications for Construction of Airports, dated June 1959 (Price $2.75) and AC 150/5370-1 Change 1, Supplement No. 2, dated 1964 (Price $0.35).

b. Department of Commerce, Weather Bureau, Technical Paper No. 40, Rainfall Frequency Atlas of the United States (Price $1.75).

4. EXPLANATION OF REVISIONS.

In addition to minor changes in text and figures, this advisory circular includes:

a. Revised minimum pipe cover requirements to reflect better information on pipe strength and the change from single wheel loads to gross aircraft loads.

b. An additional figure (Figure 3) for pipe discharge based on Manning's formula for n=0.012 to meet current pipe design requirements. Velocity grids were also added to all pipe discharge figures (Figures 3 through 8) to enhance their utility.

c. New surface flow time curves for better application in determining time of concentration.

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Chapter 1. INTRODUCTION

1. CHARACTERISTICS OF AIRPORT DRAINAGE.

a. An airport should have smooth, well-drained operational areas with sufficient stability to permit the safe movement of aircraft under all weather conditions. The design of adequate drainage for an airport is an important engineering problem because it involves extensive areas, varying soil conditions, relatively flat grades, shallow watercourses, and concentration of outfall flow.

b. The drainage system should be built before or during the grading operations because draining and grading are interrelated. A drainage system cannot be expected to function properly unless the airport area has been correctly graded to divert the surface runoff into the system. In the absence of adequate stabilization or pavement, drainage does not assure an all-weather airport, but it will shorten the interval of nonuse.

c. The large area that must be drained on an average airport requires an economically designed drainage system to realize the full value of the investment made. Sound engineering principles must be applied in the utilization of all available data, such as: topographic maps; soil reports; determinations of water tables; intensity, frequency, and duration of precipitation; climate and temperature reports; and nature of the area surrounding the particular site.

d. The topography of the site and the outlying areas affect the final layout of the runways, taxiways, aprons, and buildings. The location of these facilities will control the grading and the extent of drainage required. It is important that the grading of the airport be such that all shoulders and slopes drain away from runways, taxiways, and all paved areas. After final elevations on the airport have been determined, all surface flow of water onto the site must be intercepted and disposed of, any depressed or low spots on the site must be drained, and all surface runoff must be accumulated and directed into adequate outfalls.

e. Enough tests should be taken to identify all soil types because texture, permeability, and capillarity have a pronounced effect upon their drainability. Because of its effect on the stability of soils and on the ultimate design of the airport, the water table should be accurately determined over the entire area. When a high water table does exist, provision must be made for either lowering it or raising the finished pavement grades.

f. In designing a drainage system, it is important to determine expected precipitation at the airport site. Intensity-frequency or precipitation data may be obtained from several sources, such as: U.S. Weather Bureau, U.S. Department of Agriculture Experiment Stations, Soil Conservation Corps, State hydrographers' offices, State highway departments, or local drainage districts. These sources should be explored for records available for a particular location, because all computations in the drainage design for intensity-frequency, intensity-duration, frequency-duration, and supply data should be based on actual precipitation records.

g. Available climatological data should be studied, especially maximum and minimum temperatures, during the season when freezing and thawing normally occur. These data provide facts on depth of average frost penetration, normal amount of yearly snowfalls, and maximum and average depths of snow for winter months.

2. PURPOSE OF AIRPORT DRAINAGE.

a. The purpose of airport drainage is to dispose of water which may hinder any activity necessary to the safe and efficient operation of the airport. The drainage system should collect and remove surface water runoff from each area, remove excess underground water, lower the water table, and protect all slopes from erosion.

b. Natural drainage normally does not meet these requirements. Constructed facilities must be sufficient to provide for present requirements and any future enlargements of the system. This may mean the installation of a portion of a drainage system to supplement the natural drainage on the site or it may call for a complete system to drain the entire airport area. A proper understanding of all contributing drainage factors determines the extent of the facilities required on each particular airport.

c. An inadequate drainage system can cause serious hazards to air traffic at airports. The most dangerous consequences of inadequate drainage systems are saturation of the subgrade and subbase, damage to slopes by erosion, loss of bearing power of the paved surfaces, and excessive ponding of water.

r a shorter period. The value of A is measured .d can be accurately determined.

(2) A maximum rainfall expected once in 5 ars is generally recommended for estimating noff for airports. The damage or inconven- ıce which may be caused by greater storms is sufficient to warrant the increased cost of a 'ainage system based on a design for a storm pected once in a period longer than 5 years.

RUNOFF COEFFICIENT.

a. The runoff coefficient or factor as it is metimes designated, is the percentage of rain- ll on a given area that flows off as free water. ıis percentage will seldom reach 100 percent, en with steep slopes, because impervious sur- ces absorb some moisture and small depressions ıd irregularities hold back additional amounts. uring a storm, the percentage of runoff will crease gradually as the soil becomes saturated, e impervious areas become thoroughly wet, ıd all depressions become filled. Then the per- ntage will remain fairly constant, varying di- ctly with the intensity of the rainfall. The mposite effect of all those factors must be taken to consideration.

b. Many authorities have presented estimates r "values of relative imperviousness" for dif- rent types of urban surfaces, to be used in con- nction with their various formulas. These es- mates cover conditions applicable to the design drainage systems for large areas, usually ithin urban surroundings where the character surface is different generally from those on rports.

c. From these studies and other information ertaining to relative imperviousness of different rfaces, Table I has been compiled which ap- ars more applicable to the conditions found on rports. The appropriate runoff coefficient ould be selected from Table I for use in the rmula Q=CIA.

d. If the drainage area contributing to a cer- in inlet is composed of several surfaces for hich different coefficients from this table must assigned, the coefficient used in the formula ould be a weighted average in accordance with e respective areas. For example, if a drainage ea to an inlet consists of ½ acre of asphalt vement having a coefficient of 0.90 and 2 acres of impervious soil with turf having a coeffi of 0.35, the average coefficient for the total a is equal to $[(0.90\times0.5) + (0.35\times2.0)] \div (0.5+2.0)$ or 0.46.

6. TIME OF CONCENTRATION.

a. According to the theory underlying the Rational Method, maximum discharge at any point in a drainage system occurs when:

(1) The entire area tributary to that point is contributing to the flow.

(2) The rainfall intensity producing such flow is based upon the rate of rainfall which can be expected to fall in the time required for water to flow from the most remote point of the area to the point being investigated. The "most remote point" is the point from which the time of flow is greatest. It may not be at the greatest linear distance from the point under investigation.

b. The time at which maximum discharge occurs is referred to as the time of concentration. It is composed of two components referred to as the "inlet time" and "time of flow." The "inlet time" is the time required for water to flow overland from the most remote point in the drainage subarea to the inlet. The "time of flow" is the time during which water flows through the drainage system to any point being investigated. In some instances the "inlet time" will be the time of concentration. Such is the case for an inlet at the upper end of a drainage line.

(1) Furthermore, a condition may exist where the "inlet time" to a structure along the line may exceed the time required for water falling on a more distant subarea to reach that inlet. All areas tributary to the particular structure are not contributing until such time as water is entering the inlet from the most remote part of the individual subarea which it serves. The time of concentration, therefore, will be the "inlet time." A problem of this nature is found in the example of drainage system design in Chapter 4. Problems which arise in this regard will have to be investigated and resolved individually to determine under what conditions of time and flow the maximum volume of water can be expected at the point studied.

(2) "Time of flow" can be determined by hydraulic computation.

(3) The "inlet time," considered one of the most important factors in determining runoff, will vary with surface characteristics of the drainage area. The curves (Figure 2) will provide adequate estimates of "inlet time" for the designer. Where the particular drainage area consists of several types of surfaces, the "inlet time" must be determined by adding the respective times established for flow over the length of the several surfaces along the path from the most remote point to the inlet.

7. COLLECTION AND DISPOSAL OF RUNOFF.

a. Before any definite computations can be made toward the actual design of the drainage system, a topographical map will have to be prepared showing actual ground contours existing on the airport area. The contours preferably should be drawn to a 2-foot interval. This map should be extensive enough to show the areas surrounding the airport boundaries with all natural water courses, swales, draws, ditches, slopes, ridges and configurations. It should also show all improvements that might have a bearing on the runoff and drainage of the immediate area, such as railroads, highways, canals, and irrigation and drainage installations.

b. An additional detailed plan is necessary to show the layout of the runways, taxiways, aprons, and building area with the finished contours drawn to a 1-foot interval or less. This plan can be the "drainage working drawing." The entire system should be sketched upon it, with the outline and identification of each single subarea, all main and lateral storm pipelines, pipe sizes, direction of flow, gradients, catch basins, inlets, manholes, gutters when required, surface channels, peripheral and outfall ditches, and other essential drainage features.

c. The finished grades in conjunction with the drainage design are very important. The location of the runways, taxiways, aprons, and building area is usually fixed by the time the drainage design is started; but the cross sections of the paved areas, their profiles, and all the grades of intermediate areas should be carefully studied for their influence on the drainage layout. It is important that all finished grades be established so that every area is drainable and so that the runoff can be collected by some drainage facility.

d. The primary consideration, therefore, is the determination of a satisfactory drainage arrangement at a reasonable cost, involving the location of the shallow channels, inlets, catch basins, manholes, selection of grades, etc. Trial computations of several different drainage layouts should be made in arriving at the most practical design. When all arrangements for location of the inlets, shallow drainage swales, and storm pipes have been plotted upon the drainage working drawing, a tabulation of data and computations should be made. Such a table is further discussed in Chapter 4.

e. Normally, the inlets should be located at least 75 feet from the edge of the pavement at airports with scheduled operations and 25 feet from the edge of the pavement at airports used exclusively by general aviation. If inlets are placed close to the pavement edges, they may be bypassed by the flow of water. Also, no ponding would be possible because the impounded water could back up to the edge of the pavement and cause an undesirable condition. The grading should be planned so that the inlets can be placed normally near the edges of the landing strip or in the area midway between the runways and the parallel taxiways. The runways and taxiways should be crowned. Beyond the paved edges, the slopes should be in accordance with design recommendations. In establishing grades outside of pavements, the soil characteristics should be considered. Less grade is used for sandy soils than for other soils. It has been found desirable to have a maximum slope of 5 percent for a 10-foot width adjacent to pavement edges to facilitate rapid runoff.

f. Special treatment for the location of inlets may be necessary near some intersections, but the inlets should be as far away from the pavement as practicable. In most instances, provision should be made for small ponding areas around the inlets. Those ponding areas must be designed to present a satisfactory contour in the event planes traverse that area. This small ponding capacity at the inlets should not be recognized in the design even though such ponding should be provided for; instead, any ponding should be considered as a factor of safety which offers some protection from the occasional storm in excess of that provided for in the design.

Chapter 2. HYDROLOGY

3. RAINFALL.

a. The determination of the amounts of rainfall and runoff to be used as a basis for design of a drainage system is the primary step to be considered by the designer. The rate of storm runoff, including melting snow and ice which will flow into the system, must be established in the preliminary design stage.

b. Many investigations and studies have been conducted to find a basis for making reasonable estimates of the intensities, frequencies, and durations of rainfall for different locations. A previously used publication by D. L. Yarnell, "Rainfall Intensity-Frequency Data," is out of print. Now recommended is the U.S. Weather Bureau Technical Paper No. 40, "Rainfall Frequency Atlas of the United States," dated May 1961. The latter publication is intended as a convenient summary of empirical relationships, working guides, and maps, useful in practical problems requiring rainfall frequency data. It is an outgrowth of several previous Weather Bureau publications on this subject and contains an expression and generalization of the ideas and results in earlier papers. It is divided into two parts:

(1) The first part presents the rainfall analyses. Included are measures of the quality of the various relationships, comparisons with previous works of a similar nature, numerical examples, discussions of the limitations of the results, transformation from point to areal frequency, and seasonal variation.

(2) The second part presents 49 rainfall frequency maps based on a comprehensive and integrated collection of up-to-date statistics, several related maps, and seasonal variation diagrams. The rainfall frequency (isopluvial) maps are for selected durations from 30 minutes to 24 hours and return periods from 1 to 100 years.

c. Additional material on this subject is presented in Chapter 4. The engineer should not rely solely on the data obtained from the U.S. Weather Bureau Technical Paper No. 40. He should also get in touch with the local Weather Bureau office, city engineer's office, State highway office, State hydrographer's office, and perhaps local drainage districts or utility companies to ascertain whether additional records are available for the location under consideration.

d. Recent investigations show that results of studies regarding the probable intensity, frequency, and duration of rainfall in particular locations are more likely to be correct and conservative if they are obtained from the records of many stations rather than of one station. The center and outer limits of storms can be accurately determined only through use of a closely spaced network of rain gauges covering the vicinity traversed by the storm. More accurate predictions can be developed from the study of data for many stations in a larger area.

e. The importance of the rainfall-intensity factor is well known to drainage engineers, particularly in its relationship to total runoff. However, rainfall intensity and duration determine the amount of precipitation in any given storm. General storms are usually characterized by low intensity precipitation of long duration, whereas local storms have high rates of rainfall for short duration. Either of these types can produce approximately the same amount of precipitation. Storms of the first type, however, are the ones generally considered in airport drainage design. When practicable, the actual record of daily observations kept by the Weather Bureau should be studied. From these records may be obtained the data required in plotting an intensity-duration curve from which the rate of supply of runoff for the design may be determined. The curve is plotted from the records of excessive individual storms for the desired period of frequency. Similarly, as noted in Figure 1, a series of curves for different periods of frequency can be plotted from the records of excessive individual storms by the use of intensity per hour as ordinates and duration in minutes as abscissas.

f. When it is impracticable to obtain actual Weather Bureau data or any other supplemental records, the desired curves can be plotted by the use of the charts in the U.S. Weather Bureau Technical Paper No. 40. This may be done by spotting the airport location under consideration on the base maps of the charts. First, obtain the intensity for the location in question by interpolating between the two isohyetal lines on the chart for 30-, 60-, and 120-minute rainfalls, in inches, to be expected once in 2 years. Plot these intensities on coordinate paper (using inches per hour as ordinates and time in minutes as abscissas). To obtain the intensities for less than 30 minutes, the average relationships between 30-minute rainfall on the one hand and the 5-, 10-, and 15-minute rainfall on the other can be obtained from Table 3, page 5, Technical Paper No. 40. These relationships were developed from the data of the 200 Weather Bureau first-order stations. With a sufficient number of values plotted on the coordinate paper, a smooth curve may be drawn through the points. This curve will indicate the intensity of rainfall to be expected for any time interval from 5 minutes to 2 hours for a storm that might occur once in 2 years.

g. The same procedure is followed for occurrences of 5, 10, 25, and 50 years, plotting the results on the same sheet of coordinate paper. Figure 1 is a graph exemplifying this method. The use of the data in design is taken up later under Chapter 4 and is the basis for estimating runoff supply.

4. RUNOFF.

a. After rainfall rates have been studied, there remains a problem of determining what portion of the rainfall must be accounted for as surface runoff. The runoff rate depends on a number of conditions and is seldom constant for any given area during a single period of precipitation. The following factors have a pronounced influence on the rate of runoff from an area:

(1) Intensity and duration of the rainfall.

(2) Type and moisture content of the soil affecting infiltration.

(3) Perviousness or imperviousness of surfaces.

(4) Slope or irregularity of surfaces.

(5) Extent and condition of vegetative cover.

(6) Snow cover.

(7) Temperature of air, water, and soil.

b. Many studies have been conducted during the last decade in attempts to determine a method for estimating the amount of runoff when affected by the varying factors actually met under field conditions. The studies have covered infiltration of soils; runoff from pavement, turf areas, different length and slopes; rainfall characteristics as related to soil erosion; and numerous other conditions. Some studies have contributed valuable data toward a more comprehensive understanding of the complex problem. Until a more precise method for determining the amount of runoff from given areas is developed, the following is considered to be the practical course.

c. The Rational Method of calculating runoff is most universally applied and recommended by engineers in drainage practice. The method has come into favor because it enables the engineer to apply judgment directly to specific determinations which are subject to analysis after consideration of local conditions.

(1) The Rational Method is based on the direct relationship between rainfall and runoff. It is expressed by the equation $Q=CIA$, in which:

- Q = the runoff in cubic feet per second from a given area;
- C = a runoff coefficient depending upon the character of the drainage area;
- I = the intensity of rainfall in inches per hour;
- A = the drainage area in acres.

The value of C to be used must be based on a study of the soil, the slope and condition of the surface, the imperviousness of the surface, and the consideration of probable future changes in the surface within the area. The value of I to be selected depends upon the curves for the intensity of rainfall plotted for the local vicinity and the assumed period of recurrence, as well as the period of concentration required for surface runoff to flow from the most distant point in the area under study to the nearest inlet structure or point of collection. Design should be governed by the greatest intensity of rainfall during this period of concentration and not by some intensity

g. Inlets should be placed at all intermediate low points created by grading the airport. In the case of a long run of surface drainage where the fall is all in one direction, the inlets should be spaced so that the runoff will not travel excessive distances before reaching a structure. Normally, inlets should be spaced so that the flow from the most remote point of the drainage area is not more than 400 feet.

h. Manholes, or combination manholes and inlets, should be provided where necessary; their spacing should approximate that for inlets. In good drainage practice, manholes should be placed at all changes in pipe grades, changes in pipe sizes, changes in direction, junctures of pipe runs, and at reasonable intervals for cleanout and inspection purposes.

i. All natural watercourses, draws, and outfalls should be accurately spotted upon the drainage working drawing, and the drainage system should be planned so that as many of these watercourses as possible can be used for outfall and rapid removal of the runoff from the airport area. This procedure is necessary to prevent concentration of all of the airport runoff in one or two outfalls and flooding of property below the airport site. By use of several outfalls when they are available, the cost of the system can be held to a minimum by reducing pipe sizes and by shortening the discharge pipe runs.

j. Open peripheral ditches should be used, whenever practicable, to receive outfall flow from the drainage system, to collect surface flow from the airport site and adjacent areas, to intercept ground water flow from adjacent higher terrain, and in many cases to aid in lowering the ground water table. These open peripheral ditches should not be constructed where they will cross the extensions of landing strips. The flow across this section should be placed in conduit for at least the width of the landing strip. Before a system of peripheral ditches is planned for an airport site, the soil should be examined to determine whether the soil will erode. Open ditches have a tendency to erode because of the concentrated flow. Ditches should not be constructed where the airport is located on sand unless they are absolutely necessary, and even then, they should be shallow ditches with flat slope and immediately lined with sod to prevent erosion.

k. If the outfall drainage cannot be emptied into existing watercourses or natural drainage channels, or if the quantity of water is greatly increased over normal flow, easements or agreements should be obtained from the affected property owners to avoid future controversy.

8. FLOW IN CONDUITS.

a. After the locations of the inlets, manholes, pipe runs, and outfalls have been determined and the design runoff for all subareas has been computed, the next step in the design will be the computation (by appropriate hydraulic formulas) of the size and gradient of the pipe drains. Also, the "flow time" in the pipes from the various inlets can be computed according to the hydraulic characteristics of the pipe.

(1) Several formulas are used by engineers to determine the flow characteristics in pipes. Many of them give practically the same results, but the Manning formula is the most widely used and is recommended for use and is as follows:

$$Q = A\ \frac{1.486\ R^{2/3}\ S^{1/2}}{n}$$

in which: Q = discharge in cubic feet per second

A = cross-sectional area of flow in square feet

R = hydraulic radius in ft. $= \frac{\text{area of section}}{\text{wetted perimeter}}$

S = slope of pipe invert

n = coefficient of roughness of pipe

(2) Charts have been compiled for the solution of the Manning formula. They usually are used instead of the formula to determine the size of pipe required. Figures 3 to 8 inclusive show these charts based on Manning's formula for discharge of circular pipes flowing full, with slopes from 0.0002 to 0.2 feet per foot, and values of "n" = 0.012, 0.013, 0.015, 0.018, 0.021, and 0.024. The selection of the value of "n" in Table II is also a matter of judgment. The value selected should represent conditions which will prevail during the useful life of the line.

b. The design engineer should keep in mind that it is important to maintain sufficient velocity within the pipes to prevent depositing of suspended matter washed into the system through the inlets. The velocity of flow in pipes depends on the head or slope and the resistance to flow of the wetted portion of the pipe interior. The head or slope used in design always refers to the position of the hydraulic gradient, which is the line assumed by the top surface of the flowing water when free to rise vertically. The wetted portion of the pipe interior is used in determining the hydraulic radius, which is the area of the inside of the pipe divided by the wetted perimeter. The mean velocity of flow is used in determining the size of drains.

(1) Some engineers, when designing drainage systems, do not differentiate between the slope of the invert of the pipe and the hydraulic gradient of the pipe run. The hydraulic gradient should be considered in the design of storm drains because it is used in the solution of velocity and discharge. The hydraulic gradient at the upper end of the line should be established near the elevation of the inlet grate. The ponding volume may produce at times a higher elevation of the hydraulic gradient at this point.

(2) Past experience shows that a mean velocity of 2.5 feet per second will normally prevent the depositing of suspended matter in the pipes. Economy of design and topography will control the velocities. When lower velocities are used, special care should be taken in the construction of the system to assure good alignment, straight grades, smooth well-constructed joints, and proper installation of structures. The pipelines and slopes should be designed, wherever possible and when topographical conditions permit, so that the velocity of flow will increase progressively or be maintained uniformly from inlets to outfall. Thus the suspended matter will be carried through the system and out the outfall end.

c. The conduits in the drainage system may be constructed of reinforced concrete, concrete, vitrified clay, corrugated metal, asbestos-cement or bituminous fiber pipe. The pipes should be of conventional standard sizes and provided with either bell-and-spigot or tongue-and-groove joints in the precast pipes, and adequate metal bands for the corrugated metal pipe.

d. The chemical characteristics of water and soil which might affect the durability of drainage pipes should be investigated. The type of pipe least affected by those chemicals should then be recommended for installation.

9. STRUCTURES.

a. The structures usually built in connection with airport drainage are quite similar to those used in municipal construction. Generally speaking, the standard types are adequate, but occasionally a special type of structure will be needed. Structures located in the usable areas on airports should be so designed that they do not extend above the ground level. The tops of such structures should be one- or two-tenths of a foot below the ground line to allow for possible settlement around the structure, to permit unobstructed use of the area by equipment, and to facilitate entrance of surface water.

b. The structures most generally used are inlets, manholes, combination manholes and inlets, catch basins, lamp holes, and head walls. Some of these structures will be covered with a grate when it is necessary to admit the surface water into the system. The grates may be of cast iron, cast steel, or wrought iron. Several suggested designs of grates and inlets are shown in Figures 9 and 10. For suggested head wall details, see Figure 11.

c. The general designs of drainage structures used by the municipalities are quite alike; however, almost every large city has its own special standards which vary in details according to the desires and ideas of the design engineer. These structures all vary as to the design load they will support and should be thoroughly checked for load-carrying capacities.

d. In traffic areas, grates support loads from aircraft which will use the facility. Ground contact pressures of current and proposed civil aircraft tires approach 180 pounds per square inch. Hold-down bolts or hooks should be provided for the grates and may be of any design that prevents the displacement of the grate by traffic.

e. The inlet structures may be constructed of reinforced concrete, brick, concrete block, or rubble masonry. They should be strong enough to withstand the loads to which they will be subjected.

f. Catch basins for airport drainage are not usually considered necessary particularly when drainage lines are laid on self-cleaning grades. Under certain conditions, catch basins may be needed to prevent solids and debris from washing into the system. They should be cleaned out frequently and involve an additional maintenance problem.

g. Manholes are more or less standardized as to type and can be round, oval, square, or rectangular design. They are usually made of reinforced concrete, brick, concrete block, corrugated metal, or precast pipe sections. The design will depend on the stresses to which they will be subjected (Figure 12). Adequate unobstructed space must be provided within the manhole to enable workmen to clean out the line when necessary. Inside barrel dimensions equivalent to a diameter of 3½ feet and a height of 4 feet are usually considered sufficient, but they can be varied to suit particular situations.

h. Ordinarily, a gutter along a runway or a taxiway is not necessary because the landing strip sections should be so graded that the runoff will flow unobstructed transversely off the pavements and across the landing strip to the field inlets. In apron areas, the inlets should be placed in the valley of the pavement at proper intervals to collect the runoff.

i. Practical consideration should be given to the design of the spacing of the grate openings. The openings should be ample for the intended purpose. A slot opening of a rectangular grate should be approximately 2½ inches wide and 3 inches long. To curtail bypassing, the inlets should be installed to position the largest overall dimension normal to the direction of the flow. The area of the grate openings should be 150 percent of the area necessary to admit all of the runoff estimated for each inlet. The principle of water flow through grate openings is applied in the same manner as water flow through rectangular orifices. The formula normally used for estimating flow through orifices is stated thus:

$$Q = CA\sqrt{2gh}$$

Q = discharge in cubic feet per second

C = coefficient of discharge (approximately 0.7)

A = area of orifice or openings in square feet

g = acceleration due to gravity or 32.2′/sec./sec.

h = head on grate in feet

Chapter 3. GRADING CRITERIA

10. SELECTIVE GRADING.

a. In developing an airport, proper grading is the most important single factor contributing to the success of the drainage system. Grading and drainage plans should be most carefully coordinated. Cross sections for runways and taxiways should be developed with sloping shoulders so that the surface water is directed away from the pavements and into areas for collection and disposal. The life of the pavements and the functions of drainage can generally be improved by selective grading.

b. Before grading activities are started, the engineer should have complete soil test data of the different soils encountered on the site and data on materials from any adjacent borrow sources. As determined from the soil profile and the soil characteristics, the best types of available excavated materials should be so selected and placed to form the strongest and most drainable soil structures beneath and adjacent to the pavement. The more undesirable soils should be placed in the intermediate areas as far removed from the pavements as possible.

11. SOIL CONDITIONS.

a. When the soil survey discloses different types and strata of soils on the site, different methods and procedures in the grading and drainage construction should be considered. In grading, fills are made of the material obtained from cuts and other excavation. Therefore, a basis of design is an understanding of the nature of the soils that will be encountered.

(1) On sites where the soils are of a good pervious type and are drainable, the drainage problem is greatly simplified. This type of soil is generally the contributing factor for natural drainage. The major consideration of such a site is to determine whether an impervious strata, which might pocket the water as it percolates downward, underlies the pervious surface soils. If so, provisions must be made to remove the trapped water. Usually, though, the only consideration necessary is proper grading of the area to provide for surface runoff. The slope of the graded areas must be carefully controlled because such soils may tend to erode.

(2) Sites with impervious soils are a different drainage problem. By their nature, very little precipitation will infiltrate into impervious soil. In such cases, there is little need for any subsurface drainage. Surface drainage is required, however, and will have to be designed to take care of the estimated runoff. Some impervious soils are also subject to erosion, and this characteristic should be considered.

(3) At sites where pervious soils are superimposed on impervious soils, tests should be made to determine the extent and the profile of the top of the underlying layer. Some surface drainage will be needed and may be provided by proper grading with occasional inlets in the low areas, but some system of subdrainage is definitely required to remove the water from the top of the impervious layer. If the layer is not too far below the surface, the subdrainage pipe trenches should extend slightly into the impervious layer (approximately 6 inches) and backfilled with a granular material. The granular backfill material should be placed around and adjacent to the pipe.

(4) There are cases where an airport will be located on a site in which an impervious layer of soil is on the surface, with a pervious stratum below. Surface drainage will always be needed for draining such a site, and the system should be designed to remove all of the estimated runoff. Again, a thorough understanding of the types and extent of the soil with their respective profiles will be needed because grading operations may open up or pocket the underlying porous stratum. The underlying porous stratum often introduces underground water onto a site, requiring intercepting ditches along the edges of the airport or an intercepting drain line to cut off and divert this flow. Surface runoff sometimes may be directed into the porous layer, if it is extensive enough, by tapping through the top impervious layer with proper structures and allowing the surface water to enter the porous layer.

(5) Drainage engineers frequently find the situation in which there are irregular strata of pervious and impervious materials. The most important thing in this situation is to locate all of the pockets existing beneath the surface and to provide sufficient drains to remove the water from them. Drainage from those pockets can be piped directly from the site or fed into the surface drainage system by proper connections. In some cases it may be necessary to remove the undesirable material from the pockets, especially under and adjacent to the pavement, and to backfill with desirable material.

b. In seasonal frost areas it is important to determine the frost penetration, since the drainage pipelines should be placed below this depth whenever possible. A serious condition could develop if the drainage lines were laid above the frost penetration line. The system could become inoperative when water freezes upon contact with the drainpipes. Field determinations of frost penetration show that the depth of penetration for various soils are fairly consistant for the same location.

(1) In granular soils, frost enters the ground quicker, penetrates deeper at an earlier stage, and leaves the ground more rapidly in the spring than in a tighter clay soil. In a clay soil the frost gradually leaves in the early spring from both the top and the bottom of the frozen stratum. It finally thaws out at a point somewhere near the midsection between the ground surface and the point of deepest penetration. During this thawing-out period, the soil becomes saturated and very unstable.

(2) Frost heaving may also occur and cause damage to the drainage system. Frost heaving is the result of freezing of capillary moisture that cannot be removed by drainage from certain soils of a silty or silty sand texture. The best way to eliminate frost heave is to remove the unfavorable soil to a sufficient depth and to replace it with a suitable material not subject to frost heave.

12. LOADS ON CONDUITS.

a. In the design and construction of drainage system conduits under pavement, the maximum anticipated wheel loads should receive consideration. The pipe grades should be established to provide the necessary depth of cover, that is, the distance between the top of the pipe and the pavement. A safe design requires consideration of the probable maximum wheel load, the inherent strength of the pipe, the details of construction conditions, the type and bearing strength of the pavement, and a factor of safety. The design of airport pavements is predicated on gross aircraft weights as applied to the type of landing gear geometry, i.e., single, dual, and dual-tandem wheels. The recommended minimum depths of cover for a range of gross loads given in Table III should be used.

b. Besides the minimum depth of cover for live loads set forth in Table III, certain factors associated with installation of embankment pipe should receive consideration. The control and method of placing pipe under high embankments affect the magnitude of the resultant load. When the pipe is installed in a trench of specified width, the resultant load on the conduit is not severe or critical. When the installation does not involve a trench or where the trench width is not controlled—that is, very wide in proportion to width of pipe—the magnitude of the load becomes more critical. Because of the influence of the above installation conditions, underground conduits are classified into two major groups: trench conduits (Figure 13(a)) and embankment conduits (Figure 13(b), (c), and (d)). Embankment conduits are further subdivided into positive and negative projecting subgroups, depending on whether the conduits, as installed, are above or below the existing ground surface.

(1) Trench conduits are those which are installed in relatively narrow trenches dug in passive or undisturbed soil and then covered with earth backfill which extends to the original ground surface or for some distance above the pipe. When the conduit is placed in a trench not wider than two times its outside width and covered with earth, the backfill will tend to settle downward. This downward movement of the backfill in the trench above the conduit is retarded by frictional forces along the sides of

the trench which act upward and help support the backfill and thus reduce the dead load.

(2) Computation of actual loads on pipe installed as noted in Figure 13(b)—positive projecting conduit with the pipe placed on the natural ground elevation—shows that the results are very similar to those for pipe installed in trenches (measured at top of conduit), wider than several times the maximum outside conduit width. For both these situations, the load on the conduit could be as much as three times greater than the load on a pipe installed in a narrow trench.

(3) Between these extremes are many variations. *The closer the engineer can come to producing a trench type of installation, the more favorable are the loading conditions.* There are two methods of construction that would tend to reduce some of the load factors normally found in projection conduits. These are the negative projecting conduits and the imperfect trench, (see Figure 13(c) and (d)).

(a) The negative projecting conduits are those installed in shallow trenches of such depth that the top of the conduit is below the natural ground surface. They are then covered with an embankment which extends some distance above the ground elevation.

(b) The imperfect trench is the method of construction in which a cushion of compressible material is placed in a purposely constructed trench directly above the pipe in the interior of the embankment.

These two installations act to relieve the load on the conduit. Many designers have adopted them for placing conduits under high embankment with remarkable success.

c. The supporting strength of a conduit depends mainly on the width and quality of the contact between the pipe and the bedding, since this affects the distribution of the vertical reaction. Four classes of bedding are used for installing conduits. They are listed in the order *of their relative load distribution capability*, (see Figure 13).

(1) Class A: This method consists of placing the lower part of the conduit in a cradle of concrete having a minimum thickness under the pipe of one-fourth the nominal internal diameter and extending up the sides of the pipe to a height equal to at least one-fourth the outside diameter.

(2) Class B: This method provides that the conduit be set on fine granular material in an earth foundation carefully shaped to fit the lower part of the pipe exterior for a width of at least 60 percent of the outside diameter of the pipe. The remainder of the pipe is entirely surrounded by thoroughly compacted granular materials.

(3) Class C: This method, one most often used, requires that the earth foundation be shaped to fit the lower part of the pipe exterior with reasonable closeness for at least 50 percent of the outside diameter of the pipe. The remainder of the pipe should be surrounded by compacted granular or fine-grained material.

(4) Class D: This method requires little or no care either in shaping the foundation surface to fit the lower part of the pipe exterior or in filling and compacting all spaces under and around the pipe.

Experimental data indicate that the four classes of bedding, in the order listed above, have load factors of approximately 3.0, 1.9, 1.5, and 1.1.

d. The term "D-load" is often used to express the load on rigid pipe in pounds per linear foot per foot of internal diameter. Thus, field loads expressed in pounds per linear foot may be converted to D-load by dividing by the nominal pipe diameter in feet. The advantage of the D-load designation is that all sizes of different types and classes of pipe of a given D-load in similar bedding and installation conditions generally will support the same load.

13. EROSION CONTROL.

a. An important item in airport drainage is to provide for adequate protection of cut-and-fill slopes. Unless the slopes are correctly designed for the type of material contained in them, erosion will start during the first storm. The usual engineering practice is to establish a certain percentage of slope for the type of material encountered as shown on the soil profile and to *maintain that slope throughout the particular* section.

b. When cut-and-fill slopes are constructed to obtain the most economical section, some provision for their protection should be made. In airport construction, these slopes are usually made

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as flat as possible and vary from a 2:1 slope to one as flat as 10:1. Cut slopes more than 8 to 10 feet deep, with higher ground above them, should be provided with a cutoff surface ditch constructed several feet back from the top of the bank and running parallel to the top-of-cut line to intercept the surface water flowing down from the higher ground. To protect the cut slopes, it may be necessary to riprap, sod, sprig, or seed with rapid-growing grass or vegetation. It is good practice also to construct a ditch at the base of the bank to intercept the flow of runoff. Figure 14 illustrates several recommended types of interceptor ditches.

c. All fill-slopes that are more than 5 feet high should be protected against surface water erosion by building berms and gutters along the top of the slope to intercept the surface water and to prevent it from spilling down the slope. The surface water, thus intercepted, may be disposed of by properly constructed concrete spillways, vertical drop inlets, or other suitable means of conducting the water down the slope to proper outfall ditches. Several recommended types of embankment protection structures are shown in Figure 15. When a berm is placed along the top edge of the embankment, some method of protection is necessary, for example, by shooting the berm with a light asphaltic material, sodding the berm, or providing paved gutters. The method which most nearly satisfies local conditions should be used.

d. One oversight in the construction of the spillways has been the failure to provide an adequate cutoff wall beneath the apron at the entrance to the spillway. This cutoff is most important to prevent water from seeping under and along the spillway, and causing failure from lack of support. It is desirable to construct either a series of baffles or a stilling basin at the base of the spillway to reduce the velocity of the flowing water. The elevation at the outlet should be the same as that of the ditch into which it empties. Where open-trough type spillways are constructed, their cross-sectional area should be larger than that required for the design storm, and provision should be made in the design for ample free-board.

Chapter 4. THE DRAINAGE SYSTEM

14. BASIC INFORMATION REQUIRED.

a. In this chapter, each of the steps considered pertinent to the actual design of an airport drainage system will be considered in their respective order. A typical layout plan and the drainage criteria described before will be used. Before any design can be undertaken, certain basic information and data must be available to develop and detail the drainage system. These data should consist primarily of the following:

(1) The contour map of the airport and adjacent areas.

(2) The "drainage working drawing" showing the layout of the runways, taxiways, aprons, and building areas.

(3) All rainfall data, such as frequency, intensity, and duration of storms. If complete Weather Bureau data is not available locally, the data in U.S. Weather Bureau Technical Paper No. 40, "Rainfall Frequency Atlas of the United States," should be used. Intensity-duration curves should be plotted for storms of a 5-year frequency (considered adequate for airports) and the resultant graph used for runoff quantities in conjunction with the design. Frequency curves for periods greater than 5 years can also be plotted for checking excess storms.

(4) Plotted centerline profiles of all of the runways, taxiways, and apron areas, with necessary cross sections.

(5) Boring plans and soil profiles prepared on the basis of soil tests, including data on ground water elevation.

(6) Temperature data, especially records on maximum and minimum temperatures during seasons of freezing and thawing and on depth of frost penetration. Also, snowfall records indicating maximum and average depths of fall per month.

(7) Data, when obtainable, on the infiltration properties of soils encountered and any actual runoff records for drainage areas in the locality having similar characteristics and soils.

(8) Necessary hydraulic data, graphs, and tables for the design, including standard specifications, manufacturers' list, and information on hydraulic capacities, types, and structural characteristics for pipes, gutters, manholes, inlets, gratings, fittings and the like.

b. In the actual design, the initial step is a comprehensive study of the topographic map that is extensive enough to include the areas surrounding the airport site, to permit identifying possible contributing surface or subsurface flow, to determine general direction of flow, and to locate natural watercourses or outfalls. The existence of any major local construction or improvement that could affect drainage disposal should be evident from the map. An example is Figure 16.

c. The outline of the boundary of the airport plus the location of the special airport features such as runways, taxiways, aprons, buildings, and roads have been superimposed on the map. Possible outfalls that can be utilized for runoff are shown in the southern section and to the west of the NW/SE runway. The airport is rather flat, without any nearby outstanding high areas; for this reason there should not be any outside flow towards the airport site. There is no development in the immediate neighborhood to cause any drainage problem. As noted from the contours, the outlet pipes can be daylighted within reasonable distances and ditches can be used for outfalls.

d. As the map shows, this particular site is higher than the surrounding terrain, a situation which simplifies the drainage objective because there is no possibility of flooding. In some other airport locations where the site elevation is relatively low, there may be problems with the outfall disposal. Thus, a careful study of the topographic map will disclose the characteristics of the area terrain and the general pattern of drainage design involved.

15. DRAINAGE LAYOUT.

a. With the general configuration of the terrain well in mind, actual layout of the drainage system can now be undertaken. This can best be done on the drainage working drawing (Figure 16), upon which have been placed the runway layout and the tentative finished grading by contours drawn to a 1-foot interval. The finished contours reveal that a crown section has been used which is the standard cross section for the runways, taxiways, and landing strips. This crowned section slopes each way from the centerline of the runway on a transverse grade to the edge of the pavement, except where it becomes necessary to warp the grade to provide a smooth transition at the intersection of pavements. As noted on the typical cross section of Figure 17, the intermediate areas of the landing strip each side of the runway pavement will be on a 1½-percent transverse grade away from the pavement. This grade may be varied slightly to properly design for drainage to inlets.

b. Several trial drainage layouts will be necessary before the most economical system can be selected. The first consideration will be the tentative layout serving all of the depressed areas in which overland flow will accumulate. The inlet structures will be located, during the initial step, at the lowest points within the field areas. The pipelines will be shown next. Each of the inlet structures will be connected to the field pipelines, which in turn will be connected to the major outfalls.

c. Before proceeding further, recheck the finished contours to ascertain whether the surface flow is away from the paved areas, that the flow is not directed across them, that no field structures fall within the paved areas (except in aprons), that possible ponding areas are not adjacent to pavement edges, and that there are no excessively long distances for surface water to flow into the inlets. If there is a long gradual sloping swale between a runway and its parallel taxiway (in which the longitudinal grade, for instance, is all in one direction), additional inlets should be placed at regular intervals down this swale. Under such conditions, the dike shown in Figure 18 will protect the area around the inlet, prevent by-passing, and facilitate the entry of the water into the structure. It is also essential for all ponding area edges to be kept at least 75 feet from the edges of the pavement. This prevents saturation of the ground adjacent to the pavement during periods of ponding.

d. After the field storm drain system has been tentatively laid out and before the actual computations have been started, the areas contiguous to the graded portion of the airport which may contribute surface flow upon it should again be studied. A system of open channels, intercepting ditches, or storm drains should be designed where necessary to intercept this storm flow and conduct it away from the airport to convenient outfalls. Several types of interceptor ditches are shown in Figure 14. A study of the soil profiles will assist in locating porous strata which may be conducting subsurface water into the airport. If this condition exists, the subsurface water should be intercepted and diverted.

e. All inlets, structures, and pipelines should be identified by numbers or letters for ready reference and for use in the computation sheets. It is customary to start numbering at the outlet end of the pipeline and to progress upgrade. The areas contributing to each inlet should be outlined and the acreage determined, differentiation being made between the types of surfacing such as pavement, turf, earth, and so on. Profiles of the existing ground and final grades along the proposed drainlines should be observed and perhaps plotted; these data will be needed in determining the grades of the pipeline, see Figure 19.

f. Unless the pipe size changes, the flow line through the manholes should be uniform. Occasionally, drop manholes are installed to alleviate steep gradients on the pipeline.

g. Ditches form an integral part of the drainage system. They are so commonplace that their existence and use are taken for granted. The size of the ditches and their functions are quite variable. Their main purpose is to carry the outfall away from the pipe system and drainable areas into the natural drainage channels or into existing watercourses. Sometimes it becomes necessary to construct extensive peripheral ditches. Their purpose is to receive outfall flow from the drainage system, to collect surface flow from the airport site or adjacent areas, and to intercept possible ground water flow from higher adjacent terrain. Open ditches are liable to erode if their gradients are steep and if the volume of flow is large. When necessary, the ditches may be turfed, sodded, or lined to control erosion. A ditch when paved becomes a conduit and its design should receive sufficient consideration.

h. With the plans and data referred to in the preceding text, it is possible to design the drainage system. A step-by-step drainage procedure is as follows:

(1) Identify the structures and establish the lengths of pipe segments between structures. Scaled dimensions are of sufficient accuracy.

(2) Select values for coefficients of runoff "C" for the several types of surfaces over which water will flow. Table I may be used as a guide in arriving at acceptable values for this factor.

(3) Compute a weighted value of "C," if required, as explained under "Runoff Coefficient," paragraph 5.

(4) Determine the distance from the inlet to the most "time-remote" point in the tributary subarea. If in flowing from such point, water traverses different types of surfaces, the lengths of flow over each type of surface should be determined.

(5) Using the distances determined according to step (4), the time of flow to the inlet from the most "time-remote" point can be established. The time so determined is the "inlet time." It may be obtained by the use of the curves in Figure 2. Keep in mind that the total length of overland flow may consist of several sublengths, each of different surface or slope.

(6) Determine the time of concentration for the inlet in accordance with the principles outlined under "Time of Concentration," paragraph 6.

(7) From the plotted rainfall curve for the design storm, find the rainfall intensity "I" for the corresponding time of concentration.

(8) Record the acreage of the subarea which is contributing to the inlet.

(9) Compute the quantity of runoff by the formula Q=CIA. This is the amount of water which must be accommodated by the drain pipe from this inlet.

(10) Select slope and determine the p size which will carry the runoff. Charts shown in Figures 3 through 8 may be used.

i. As the design progresses along the line, runoff naturally accumulates. Each succeed pipe run carries the water from the upper rea of the system in addition to the water introdu through its immediate inlet structure. This cumulation, however, is not necessarily a strai arithmetic summation of flows from preced inlets. Flow from influent lines may have be adjusted to represent the amount of w which they are contributing at the time of c centration for the point being investigated.

16. SURFACE DRAINAGE.

a. A portion of the actual design of the sys can now be considered in accordance with crit and data given previously. For example, area between the apron and taxiways of the port layout has been selected for detail anal in making the necessary calculations and deter nations, (see Figure 20).

b. The rainfall data for the location un study has been obtained from graphs simila those found in the U.S. Weather Bureau T nical Paper No. 40. These data have been plo and curves drawn (Figure 1) to indicate the tensity of rainfall. The curve of the intens duration for a 5-year frequency will be use the computations. From this curve, the inten for the corresponding time of concentration each inlet can be readily determined and use the system design.

c. After the drainage layout has been dec and sketched on drainage working drawings, extent of the subarea contributing to each in structure is measured and tabulated. The rec ing of the sizes of the subareas is shown in T IV. Inspection of the areas will show that face water will flow partly over pavements partly over turfed areas. A runoff factor of has been assumed for the paved areas and for the turfed areas. A weighted value of factor "C" or runoff coefficient was calculate explained in Chapter 2 and is shown in Table In working up the data shown in Table V, a and-spigot type of concrete pipe was used a value of n=0.015 was assumed.

'or convenience in the computations and ing the results, a form such as that of V is suitable. Explanation of the various ıs of this form is as follows:

) Column 1 identifies the inlet being inıted. All structures should be numbered, ably starting with the first structure from tfall and progressing along the line to the nost end.

) Column 2 identifies the particular segof the drainage system being designed.

) Column 3 is the length of that segment line.

) Column 4 is the "inlet time," or time ›d for water to flow overland from the emote point of the tributary subarea to et being considered.

) Column 5 is the "flow time" through the ılar pipe segment. This is obtained by ıg the pipe length by the velocity of the See Column 12 for velocity.

) Column 6 is the time of concentration. ılets 12 and 13 in the example, time of tration equals the "inlet time." Maximum oes not occur at inlet 11 until all areas ry to it are contributing to that inlet. All ıre contributing to inlet 11 in 43.7 minutes, ote in Table V).

) Column 7 is the coefficient of runoff for ›area contributing to the inlet. A method ermining the runoff factor is illustrated in IV.

) Column 8 is the rainfall intensity based time of concentration and the design frequency, (from Figure 1).

) Column 9 is the acreage of the subarea iately tributary to the inlet being investi- (See Table IV.)

0) Column 10 is the amount of runoff from ibutary area as determined by the Rational l formula Q=CIA.

1) Column 11 is the accumulated runoff must be accommodated. In the example n the maximum accumulated runoff to be ged from inlet 11 consists of the runoff he subarea tributary to inlet 12, plus the of runoff from the subarea tributary to 1. The total accumulated runoff at inlet own in the table.

(12) Column 12 is the velocity of flow through the pipe, determined by dividing the pipe capacity by the area of the pipe, or using the nomograph, Figure 21. To be selfcleaning, drains should be designed to have a flow velocity of not less than 2.5 feet per second.

(13) Column 13 is the size of the pipe required to accommodate the flow.

(14) Column 14 is the slope of the pipe. Selection of the slope usually will be governed by such factors as topography, amount of cover, depth of excavation, desired discharge velocity, and elevation of discharge basin or channel.

(15) Column 15 is the capacity of the pipe in cubic feet per second on the slope indicated. Obviously, the capacity must exceed the accumulated runoff if the system is to operate properly, (use Figures 3 through 8).

(16) Column 16 is the invert elevation of the structure.

(17) Column 17 is available for any remarks pertinent to the design.

e. It is obvious that many combinations of pipe sizes and slopes can be selected which will provide the required pipe capacity. It is good practice to select the smallest size pipe, consistent with such considerations as economy of excavation and flow velocity, that will accommodate the desired discharge. Usually 12-inch pipe is the minimum size used to carry surface runoff. It is the general practice to increase pipe size as the volume of water to be accommodated increases. The velocity in the entire system should be maintained or increased progressively along a line to prevent settlement of suspended solids. Care should be taken to avoid flow retardance or the creation of turbulence in the system as this also will cause settlement of suspended solids.

f. A form similar to that described may be used in the design of any of the several sections of the system. The desirability of using ponding areas should be studied and the system should be checked for its capability to take care of storms heavier than the design storm.

17. PONDING.

a. The rate of outflow from a drainage area is limited by the capacity of the drainage facility serving the area, usually a drainpipe. Whenever the rate of runoff at a structure such as an inlet exceeds the drain capacity, a temporary storage or ponding occurs. As soon as the rate of inflow into a ponding basin becomes less than the drain capacity, the accumulated storage will be drawn off at a rate equal to the difference between the capacity and the rate of inflow. The rate of outflow from a ponding basin is affected somewhat by the elevation of the water at the drain inlet, and it will increase as the head on the inlet increases. Because of the flat slopes on an airport, the surface areas of the storage basins surrounding the inlets are usually very large in comparison with water depth at the inlets. Although the hydraulic gradient at the inlet is raised slightly because of ponding, any increase in drain capacity should be considered a small factor of safety and not taken into account.

b. Figures 22 and 23 and Table VI have been prepared to illustrate the proposition of ponding. For example, the area to be drained is part of that shown in Figure 20 except that the contours have been changed to create one large ponding area with only one drain to handle all the runoff. The size of the drain can be varied to compute the different time periods needed to discharge the volume of ponding accumulated.

c. A study of the cumulative rainfall for 5-year and 10-year frequency will be used as the rate of supply. The rainfall usually diminishes gradually in intensity after a couple of hours. Shown in the table is the tabulation of the hourly intensity in inches for various intervals for both the 5-year and 10-year frequency. Also shown are all the necessary data for the cumulative runoff for the two frequencies, and the discharge for a 33-inch diameter pipe. These data have been plotted in Figure 23. Also plotted are the discharge capacities for 21-inch, 24-inch, and 30-inch pipes.

d. Computations indicate that if the inlet is constructed to an elevation slightly below contour 534, there will be a ponding storage capacity between it and contour 536 of 243,300 cubic feet. From Figure 23, it can be seen that the 33-inch pipe will empty the area in 47 minutes after the start for the cumulative runoff from the 5-year frequency storm and will empty the area in 64 minutes after the start for the cumulative runoff from the 10-year frequency storm. The 21-inch pipe would provide sufficient discharge to keep the maximum ponding down to 102,500 cubic feet after 60 minutes after the start of the runoff for the 10-year frequency storm; however, this pipe would not empty the ponding area for an additional 3 hours or more.

e. In view of these considerations, it appears that the 33-inch pipe could be reduced in size, since the smaller diameter pipe shown can dispose of the ponded volume. However, the smaller pipe could cause the retained runoff to be ponded for a considerably longer interval of time. This is based on the assumption that the rate of runoff is uniform, which is not entirely true because the pavement, the high and low spots, the thick and thin turf, and the variable intensities will affect the time of concentration. Generally speaking, the peak runoff can be assumed to follow the peak rainfall by a definite lag in time.

18. SUBSURFACE DRAINAGE.

a. Subsurface drainage to be considered on airports consists, in general, of providing intercepting drains to divert subterranean flows, draining wet masses or areas, controlling moisture in the base or subbase of pavement or any combination of these. Draining large field areas by subsurface drainage is not usually necessary on airports, since it can be done more efficiently by grading properly and installing surface drainage. Subdrains should be designed to function as subsurface drains only and should not operate to remove surface drainage.

b. The presence of a high-water table on an airport site calls for a thorough soil survey and a determination of the cause of such underground water. The table may be extensive or be located in one or more isolated portions of the site. The soil horizons and types of soil will definitely reveal whether it is:

(1) pocketed in pervious soils over impervious stratum,

(2) in low areas of an undulated impervious stratum,

(3) confined within a porous waterbearing stratum, or

(4) within a high flood plane of a stream or watershed.

In many locations the water table fluctuates with the seasonal rainfall. This should be checked when making the soil survey. Conditions 1 and

2 can generally be best relieved by the use of subsurface drains placed within the actual areas having the high-water table. Conditions 3 and 4 are usually remedied by correctly placing intercepting surface ditches to cut across the porous water-bearing stratum, or to install intercepting drain lines, occasionally supplementing either with subsurface drains within the area affected. Figure 24 illustrates types of subsurface installation that have proved satisfactory.

c. Even though a very thorough soils survey of the site has been made, the presence of free-flowing water should be noted during construction. When encountered, proper action should be taken to collect and dispose of it. If free-flowing water is found in only a small area, the drain line may be carried to an appropriate outfall. If that solution is not found to be practical, the line may be connected to the sealed surface system by a connection similar to that shown in Figure 25. Care must be taken to prevent the water in the sealed system, when flowing full, from backing up into the subdrainage line and saturating the area contiguous to the subdrain.

d. Certain types of soils are self-draining, some can be drained by artificial means, and others are not drainable.

(1) Soils such as gravelly sand, sand, silty sand, and some types of clay sands are often self-draining.

(2) Soils like sandy clay, clay silts, and certain sandy silts are drainable, and subsurface drains will be effective. The percentage of sand in these soils determines their ability to be drained.

(3) Soils composed of silt or clay without a sand content such as silty clay, silt, and clay are difficult or impossible to drain.

e. It is important, during grading operations, to place the best drainable type of soils available adjacent to or beneath the paved areas. This will form the strongest soil structure where it is most beneficial and, at the same time, will provide drainage away from the base and subbase. The poorer undrainable types of soils should be moved to non-traffic areas.

f. Figure 24 illustrates several different types of subdrainage systems often used on airports. These are only examples. The particular type to install will depend upon the actual conditions at each airport site. A review of the soil survey data during construction is the only safe way to determine the proper type of subdrainage system.

g. The design of a subsurface drainage system is somewhat similar to that of a surface drainage system. The runoff from a subsurface system is considerably less than for other types, and the grades are usually flatter. The grades should not be less than 0.10 foot in 100 feet. The type of surface, the soil, the infiltration, the spacing and depth of the drains, the amount of precipitation or seepage, and other factors all affect the runoff and, therefore, the size of the pipe needed.

(1) A runoff for subdrainage that is commonly used is 0.25 to 0.50 of an inch in 24 hours. A runoff of 0.25 inch per acre in 24 hours is equal to 0.0105 cubic feet per second for each acre.

(2) When the rate of runoff is known the proper size of pipe may be determined from Figures 3 through 8.

h. The types of pipe used for subdrains are: plain or perforated vitrified clay or concrete pipe, perforated corrugated metal pipe with bands, cradle invert vitrified clay pipe, perforated asbestos-cement pipe, and perforated bituminous-fiber pipe.

i. A type of subdrainage installation considered important in many localities for the protection of the base and subbase of the runways and taxiways is the intercepting drain. This drain should be placed across and at the lowest portion of the seepage stratum in order to cut off and divert the entire flow. The drain should seldom, if ever, be placed under the pavement proper.

j. The control of moisture under pavement is the principal reason for subsurface drainage along the pavement edges. Free water may collect below the pavement under several different conditions. The water table may rise into the base or subbase during an exceptionally wet season, or it may be high enough to supply capillary water to the top of the subgrade. Frost layers contribute free water when they thaw out and this water should be carried away by proper drains. This can be done by connecting the pervious base and subbase of the pavement with the backfill material in the subdrain system. The subsurface drains should be installed in accordance with "C" in Figure 25. As shown on the drawing, these drains need not be large; and, under normal conditions, a pipe of 6 or 8 inches in diameter will suffice.

k. The construction specifications should require backfilling the trenches with well compacted granular material. To prevent the possibility of large quantities of surface water entering these drains, the pervious backfill material surrounding the drains should not extend to the top of the trench.

l. The filter material requirement should be carefully considered because the quantity of water to be handled by these subdrains is relatively small and it is possible that the surrounding natural soil may filter into interstices of the filter material. The following should be considered in filter and underdrain design:

(1) A fine material will not wash through a filter material if the 15-percent size of the filter material is less than 5 times as large as the 85-percent size of the fine material.

(2) In addition to meeting the above size specification, the grain size curves for filter and fine material should be approximately parallel in order to minimize washing of the fine material into the filter material.

(3) Filter materials should be packed densely, to reduce the possibility that movement of the fines might cause any change in the gradation.

(4) A filter material is no more likely to fail when flow is upward than when flow is in some other direction, unless the seepage pressure becomes sufficient to cause flotation or a "quick" condition of the filter.

(5) A well-graded filter material is less susceptible to running through the drain pipe openings than a uniform material of the same average size. However, even a filter material having a wide range of gradation cannot be used successfully over a drain pipe having a large opening, since enough fine particles to cause serious clogging will move out of the well-graded filter into the pipe.

(6) Large openings in the drain pipe tend to increase the rate of infiltration, but also increase the tendency for filter material to collect in and clog the pipe.

(7) Where it is feasible to design and use two gradations of backfill consisting of separate layers with coarse aggregate near the openings of the pipe, pipes with larger openings would probably operate satisfactorily.

m. Figure 26 is a graph of the gradation of a sample soil that is uniformly graded, and another that is well graded. It also shows the uniform filter material required for backfill to prevent infiltration of the uniform soil into the filter material. Also shown is the well-graded filter material required for backfill that will prevent infiltration. This graph is an example to illustrate the factors discussed.

(1) To use the graph, follow along the curve drawn for the well-graded soil to a point where 85-percent size passes the 0.25 millimeters. Then follow along the curve drawn for a well-graded backfill to where 15-percent size passes a certain sieve. It will be noted that it is the 1.25 millimeter size. This also holds true for uniform material curves if the 85-percent size of the uniform soil is multiplied by 4 to check with the 15-percent size of the uniform backfill material.

(2) To use a graph of this type, the natural soil should be screened for a mechanical analysis and the gradation curve plotted. Then establish the 15-percent size of the backfill material just less than 5 times the 85-percent size of the natural soil, and construct a curve for the backfill material parallel to the original soil curve. This will be the curve of the gradation of the backfill material desired.

(3) It will be noted from a study of Figure 26 that there will be a separate and distinct gradation curve for each type of soil analyzed. Consequently, there will be a separate gradation curve for the backfill material to use with each soil type. The limiting piping ratio for a uniform soil is 4, and for a well-graded soil is 5, and a backfill material with a parallel gradation curve not exceeding the piping ratio will prove satisfactory in preventing infiltration. If the specifications are written so that the gradation for the backfill material follows the exact curve drawn parallel to the soil gradation curve with its required piping ratio for each type of soil, it will be seen that the graded backfill material will be very difficult to produce commercially. Figure 27 illustrates several soil gradation curves and also indicates the theoretical curve (Number 5) with a piping ratio of 5 for the backfill material for soil type No. 4. Also plotted on the

graph are the specification limits for commercial size concrete sand and concrete coarse aggregate. The theoretical gradation curve for backfill material with a piping ratio of 5 falls between these two limits of commercial size for aggregates.

(4) A backfill material is safe to use if the gradation curve for that material indicates that the particle sizes are less than the plotted theoretical gradation curve with a piping ratio of 5 for any particular soil. Figure 27 indicates that the specification limits of commercial size concrete sand meet this requirement for the well-graded soil No. 4. A preliminary investigation should be made in the locality of the site to determine the type and gradation of concrete sand available. If the sand falls within the limits shown, it should be used for backfill material.

(5) Certain installations will require the specifying of two separate sizes of backfill materials. The example shown in Figure 27 contemplates the use of the commercial size concrete sand for the backfill material adjacent to the well-graded soil No. 4 to prevent infiltration. Because the openings in the drain pipe would allow the finer backfill material to enter the pipe if placed directly against it, a larger size material which will not enter the pipe nor allow displacement of the finer backfill material should be placed adjacent to the pipe.

(6) Using the same procedure as was used to establish curve No. 5, the safe gradation is determined for the coarse backfill material by using Figure 27 again. A theoretical gradation curve (No. 7) with a piping ratio of 5 is constructed for the finer backfill material. Use the finer side of the gradation band for the concrete sand as the reference curve (No. 6) for this new gradation curve, since the percentage of the smallest size will indicate the material most difficult to control. This new curve No. 7 indicates that the commercial size concrete coarse aggregate will satisfactorily prevent infiltration of the fine backfill material and will not enter the pipe. With openings in pipe rarely exceeding ¼ inch and with the arbitrary piping ratio of 5, a factor of safety is provided for use in actual field conditions.

19. CONSTRUCTION.

The usual construction work associated with a drainage system includes such items as excavation, trenching and shoring; preparation of bedding, laying, aligning and jointing of pipe; (Figure 29, Methods of Laying Drainage Pipe) backfilling and compacting; installing structures; and cleaning up. A successful and efficient airport drainage system should be well designed and should be constructed in accordance with the requirements of AC 150/5370-1, *Standard Specifications for Construction of Airports.* Quality construction which is attained by consistently using proper and accepted construction methods and practices along with adequate inspection ensures a drainage system that functions properly. Poor construction leads to progressive deterioration and endless maintenance and reconstruction problems.

20. MAINTENANCE OF THE SYSTEM.

a. Maintenance is essential to preserve and prolong the service and utility of all drainage facilities. All structures and visible units of the system should be inspected frequently, and the malfunctionings should be immediately corrected. Several items that will need constant checking are: the inlet grates for clogging by grass cuttings, sticks, ice, and debris; the catch basins and pipelines for stoppage by sediment, and waste; settlement around pipes and structures from infiltration; stoppage in outfall ditches; erosion around structures in watercourses or embankments; high shoulders on pavements or structures; and any damage to the structures. A little maintenance at the right time may prevent major repairs later.

b. A qualified member of the airport personnel should be selected to be in charge of all drainage maintenance matters. He should be provided with sufficient and suitable equipment, tools, materials, supplies, and labor for necessary maintenance and repairs. Periodic inspections should be made, including a patrol of the system during or after a storm if conditions do not seem normal. As a minimum program, a complete inspection should be made in the fall in preparation for winter, and another in the spring to determine the extent of maintenance needed. Proper inspection and maintenance require familiarity with design, capacity, and location of drainage facilities.

c. *Mechanical devices for cleaning drain lines* of silt, sand, and other debris include various cutters, brushes, scoops, scrapers, and screws which are drawn through by hand or power-operated windlasses. These tools, some of which are adjustable, are available to fit all sizes of pipes. Sectional sewer rods with working and flushing heads can be used alone or with cutting devices. One flushing method often used is by blocking all openings in a manhole, filling it with water, and then quickly removing the block at the outlet. The rapid flow of the released water usually will clean the pipe.

d. When ditches alone or in combination with natural watercourses comprise the surface drainage system, they should be properly maintained. Ditch slopes should be maintained to the original design slope. Where possible, a dense turf should be developed to stabilize open ditches. The dense turf should be mowed frequently as tall growth decreases flow. Ditches should be kept free of weeds, brush, logs, silt, and other debris which might divert or restrict the flow at any time.

e. When maintenance of an airport is being considered, the entire area within its boundary should be included. Any obstruction which could alter the designated flow should be changed, corrected, or removed. One item that will be objectionable and require periodic correction is high shoulders along the pavement edges. Any formation of deep ruts may on occasion concentrate the runoff to an undesirable extent. Some surface obstruction may cause the flow to channelize and start erosion. Such conditions should be corrected. In patrolling the airport, attention should be given to the adequacy of the drainage design. Proper inspection might disclose that some portions of the waterways and structures could require enlarging, replacing, or additions. It is generally good practice and more economical to make minor corrections when the faults are detected, rather than to have major, expensive maintenance repairs later.

TABLE I
VALUE OF FACTOR "C"

Type of Surface	Factor "C"
For all watertight roof surfaces	.75 to .95
For asphalt runway pavements	.80 to .95
For concrete runway pavements	.70 to .90
For gravel or macadam pavements	.35 to .70
For impervious soils (heavy) [1]	.40 to .65
For impervious soils, with turf [1]	.30 to .55
For slightly pervious soils [1]	.15 to .40
For slightly pervious soils, with turf [1]	.10 to .30
For moderately pervious soils [1]	.05 to .20
For moderately pervious soils, with turf [1]	.00 to .10

[1] For Slopes from 1 percent to 2 percent.

TABLE II
COEFFICIENT OF ROUGHNESS

PIPE	
Clay and Concrete	
Good Alignment, Smooth Joints, Smooth Transitions	0.012
Less Favorable Flow Conditions	0.015
Corrugated Metal	
100% of Periphery Smoothly Lined	0.013
Paved Invert, 50% of Periphery Paved	0.018
Paved Invert, 25% of Periphery Paved	0.021
Unpaved, Bituminous Coated or Non-coated	0.024
OPEN CHANNELS	
Paved	0.015 to 0.020
Unpaved	
Bare Earth, Shallow Flow	0.020 to 0.025
Bare Earth, Depth of Flow Over 1 Foot	0.015 to 0.020
Turf, Shallow Flow	0.06 to 0.08
Turf, Depth of Flow Over 1 Foot	0.04 to 0.06

TABLE III
MINIMUM DEPTH OF COVER FOR PIPE—IN FEET
Flexible Pavement

CLAY STANDARD

Dia. (inch)	A	B
12	3.0	---
24, 36	3.5	---

CONCRETE NONREINFORCED STANDARD

Dia. (inch)	A	B
12	3.0	---
24	3.5	---

CONCRETE NONREINFORCED EXTRA STRENGTH

Dia. (inch)	A	B
12	2.0	5.0
24	2.5	7.0

CLAY EXTRA STRENGTH

Dia. (inch)	A	B
12	2.0	5.0
24	2.0	5.5
36	2.5	7.0

ASBESTOS-CEMENT CLASS I

Dia. (inch)	A	B
6	1.5	2.5
8	1.5	3.0
10	1.5	4.5
12	2.0	5.5
14, 16	2.5	---
18, 20	3.5	---
24, 30	4.5	---
36	5.0	---

ASBESTOS-CEMENT CLASS II

Dia. (inch)	A	B
10, 12	1.5	3.5
14, 16	1.5	3.5
18	1.5	4.0
20	1.5	4.5
24	2.5	6.0
30, 36	2.5	---

CONCRETE REINFORCED

CLASS	A	B
I	---	---
II	3.5	---
III	2.5	---
IV	2.0	4.5
V	1.5	3.5

CORRUGATED METAL PIPE

Gage	Dia. (inch)	A	B
16	12	1.5	2.5
16	24	2.0	4.5
16	36	2.5	---
16	48	2.0	4.0
16	60	2.0	5.0
14	12	1.0	2.0
14	24	1.5	3.0
14	36	2.0	4.0
14	48	1.5	3.0
12	24	1.0	2.0
12	36	1.5	2.5
12	48	1.0	2.0
12	60	1.0	2.5
10	36	1.0	2.0
10	60	1.0	2.0
10	72	1.0	2.0

BITUMINIZED FIBER

Dia. (inch)	A	B
6	2.0	4.5
8	2.0	5.0

1. A=30,000 lb. maximum gross aircraft weight/single-wheel gear or 50,000 lb. maximum gross aircraft weight/dual-wheel gear.
2. B=350,000 lb. maximum gross aircraft weight/dual-tandem-wheel gear.
3. Cover depths are measured from top of flexible pavement or unsurfaced areas to top of pipe.
4. Pipe placed under rigid pavements shall have a minimum cover, measured from the bottom of the slab, to top of pipe as follows: 1.0 foot cover for A-type loading; 1.5 foot cover for B-type loading.
5. Use A-type loading cover requirements in areas not used by aircraft.
6. Tabulated depths of cover do not provide for freezing conditions.
7. Dashes (---) in table indicate that pipe will not meet strength requirements.

TABLE IV

DESIGN DATA FOR DRAINAGE EXAMPLE IN TABLE V

Inlet No.	Tributary Area To Inlets (in acres)				Distance Remote Point To Inlet (in ft)			Time For Overland Flow (in mins.)		
	Pavement	Turf	Both	Sub Total	Pavement	Turf	Total	Pavement	Turf	Total
12	4.78	9.91	14.69	14.69	100	790	890	4	37	41
11	5.48	9.24	14.72	29.41	90	750	840	4	36	40
10	1.02	10.95	11.97	41.38	65	565	630	3.5	31.3	34.8
13	1.99	19.51	21.50	21.50	110	1140	1250	4.3	44.3	48.6
9	1.46	14.59	16.05	78.93	85	612	697	3.9	32.4	36.3
Totals	14.73	6420	78.93							

Weighted Average For "C" For Tributary Area To:

To Inlet (12)

$$\frac{4.78}{14.69} \times 0.90 = 0.29$$

$$\frac{9.91}{14.69} \times 0.30 = \underline{0.20}$$

$$C = 0.49$$

To Inlet (10)

$$\frac{1.02}{11.97} \times 0.90 = 0.08$$

$$\frac{10.95}{11.97} \times 0.30 = \underline{0.27}$$

$$C = 0.35$$

To Inlet (11)

$$\frac{5.48}{14.72} \times 0.90 = 0.34$$

$$\frac{9.24}{14.72} \times 0.30 = \underline{0.19}$$

$$C = 0.53$$

To Inlet (13)

$$\frac{1.99}{21.50} \times 0.90 = 0.08$$

$$\frac{19.51}{21.50} \times 0.30 = \underline{0.27}$$

$$C = 0.35$$

To Inlet (9)

$$\frac{1.46}{16.05} \times 0.90 = 0.08$$

$$\frac{14.59}{16.05} \times 0.30 = \underline{0.27}$$

$$C = 0.35$$

TABLE V

DRAINAGE SYSTEM DESIGN DATA

1 Inlet	2 Line Segment	3 Length of Segment FT	4 Inlet Time MIN	5 Flow Time MIN	6 Time of Concentration MIN	7 Runoff Coefficient "C"	8 Rainfall Intensity "I" IN/HR	9 Tributary Area "A" ACRES	10 Runoff "Q" CFS	11 Accumulated Runoff CFS	12 Velocity of Drain FT/SEC	13 Size of Pipe IN	14 Slope of Pipe FT/FT	15 Capacity of Pipe CFS	16 Invert Elevation	17 Remarks
12	12-11	510	41	2.7	41	0.49	2.40	14.69	17.28	17.28	3.18	33	.0017	18.90	530.65	(n = 0.015)
11	11-10	852	40	5.0	43.7	0.53	2.31	14.72	18.02	35.30	2.84	54	.0007	45.00	528.03	See note below
10	10-9	550	34.8	3.3	48.7	0.35	2.15	11.97	9.01	44.31	2.84	54	.0007	45.00	527.44	See note below
13	13-9	730	48.6	3.7	48.6	0.35	2.16	21.50	16.25	16.25	3.27	33	.0018	19.40	530.11	
9	9-OUT	1145	36.3	5.9	52.3	0.35	2.03	16.05	11.40	71.96	3.24	66	.0007	77.00	526.05	
OUT															525.25	

NOTE: Time of concentration for Inlet #11 is 43.7 minutes (41 + 2.7 = 43.7) which is the most time remote point for this inlet. Likewise time of concentration for Inlet #10 is 48.8 minutes (41 + 2.7 + 5.0 = 48.7)

TABLE VI

COMPUTATIONS FOR PONDING EXAMPLE IN FIGURES 22 AND 23

Hourly Intensities for Various Time Intervals from Figure 10

Time	5 yr. Frequency	10 yr. Frequency
5 min.	5.76	6.48
10 min.	4.92	5.70
15 min.	4.24	4.76
20 min.	3.72	4.19
30 min.	2.92	3.38
60 min.	1.87	2.28
90 min.	1.36	1.73
120 min.	1.09	1.40
180 min.	0.81	1.02

Q = CIA
A = 4.48 Acres, Pavement
= 45.04 Acres, Turf
= 49.52 Acres, Total
C = 0.90 For Pavement
= 0.30 For Turf
I = 2.00 In. (From Fig. 10 for 55 min.)
Q = 0.354 x 2.00 x 49.52 = 35.06 c.f.s.
n = 0.015 S = 0.7 % 33" pipe will carry 38 c.f.s.

Distance most remote point – 1600'
120' across pavement, 1480' across turf
Concentration Time: 4.5 + 50.5 = 55 minutes

$$\text{Average } C = \frac{4.48 \times 0.90}{49.52} + \frac{45.04 \times 0.30}{49.52} = 0.354$$

CA = 49.52 x 0.354 = 17.53
Runoff rate when all areas contributing
1 hr. = 3600 x 38 = 136,800 c.f

Cumulative Runoff in cu. ft.
I = 5.76 (From above)
Q = CIA CA = 17.53
Q = 17.53 x 5.76 = 100.97 c.f.s.

For 5 min. for 5 yr. frequency
5 min. = 300 seconds
100.97 x 300 = 30292 cu. ft.

Thus:

Minutes	5 yr. Frequency	10 yr. Frequency
5	17.53 x 5.76 x 300 = 30292	17.53 x 6.48 x 300 = 34078
10	17.53 x 4.92 x 600 = 51749	17.53 x 5.70 x 600 = 59953
15	17.53 x 4.24 x 900 = 66894	17.53 x 4.76 x 900 = 75098
20	17.53 x 3.72 x 1200 = 78254	17.53 x 4.19 x 1200 = 88141
30	17.53 x 2.92 x 1800 = 92138	17.53 x 3.38 x 1800 = 106653
60	17.53 x 1.87 x 3600 = 118012	17.53 x 2.28 x 3600 = 143886
90	17.53 x 1.36 x 5400 = 128740	17.53 x 1.73 x 5400 = 163765
120	17.53 x 1.09 x 7200 = 137575	17.53 x 1.40 x 7200 = 176702
180	17.53 x 0.81 x 10800 = 153352	17.53 x 1.02 x 10800 = 193110

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INTENSITY CURVES FOR STORMS IN VICINITY OF EXAMPLE SITE

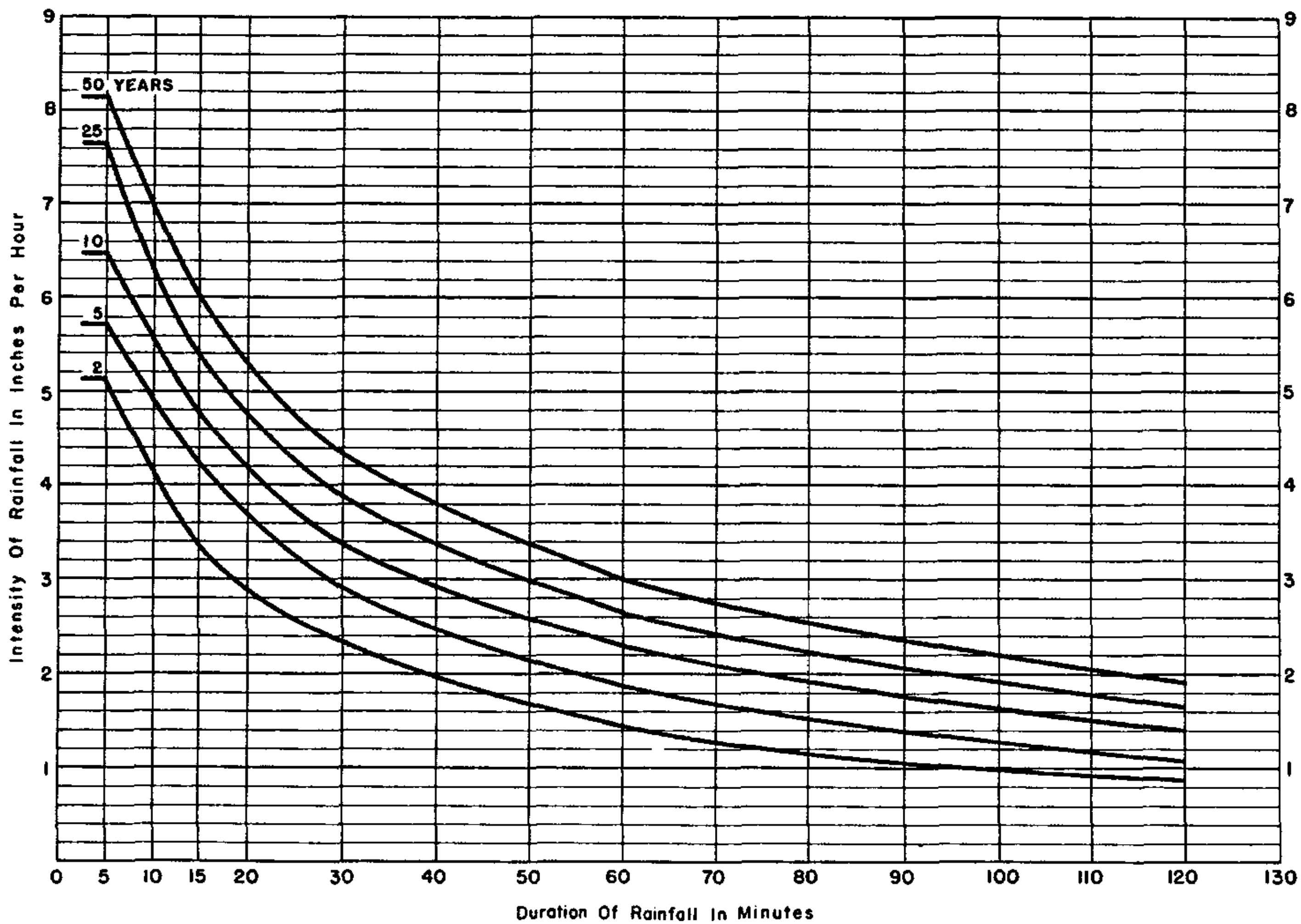
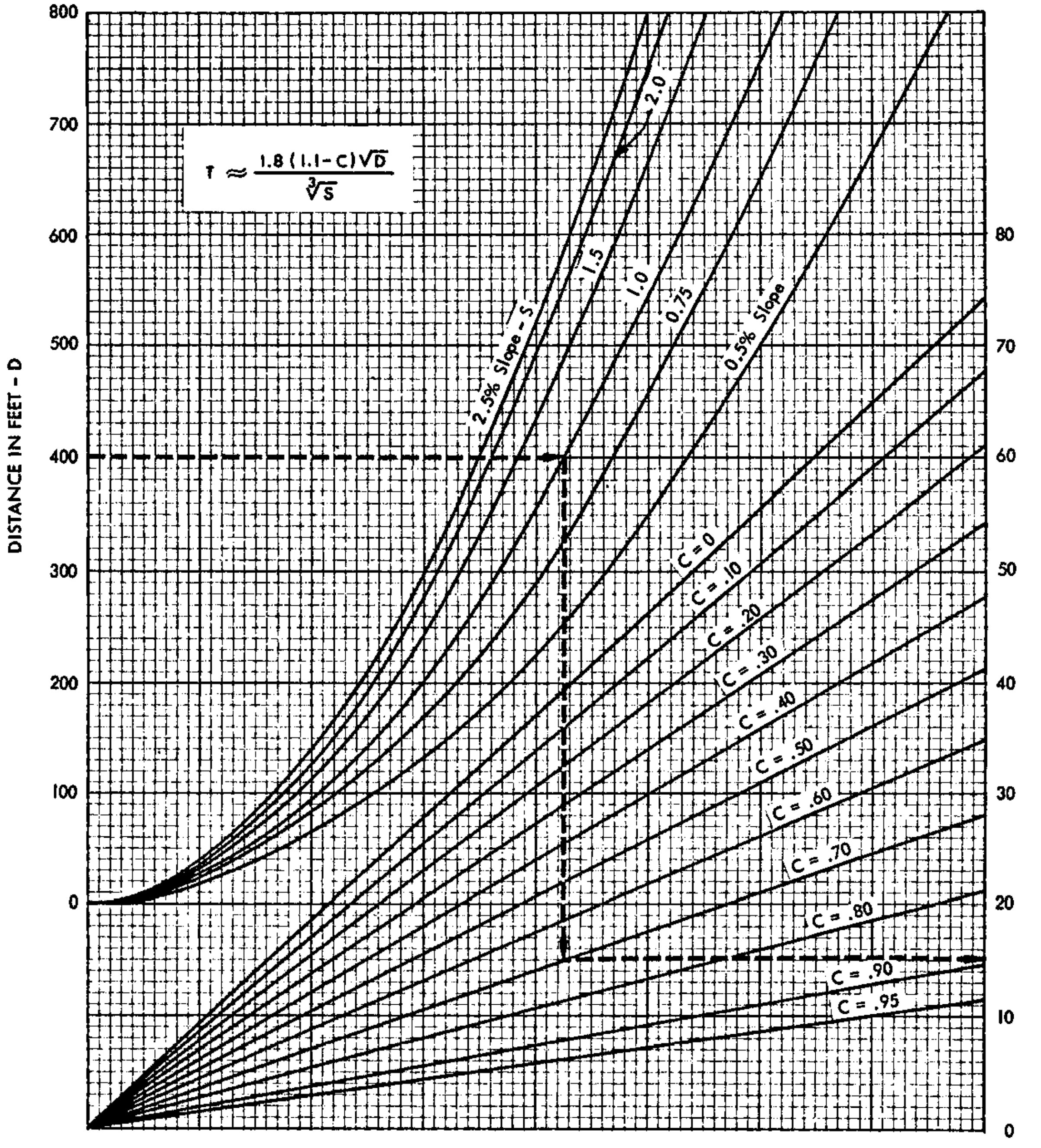


Figure 1



Surface Flow Time Curves

Figure 2

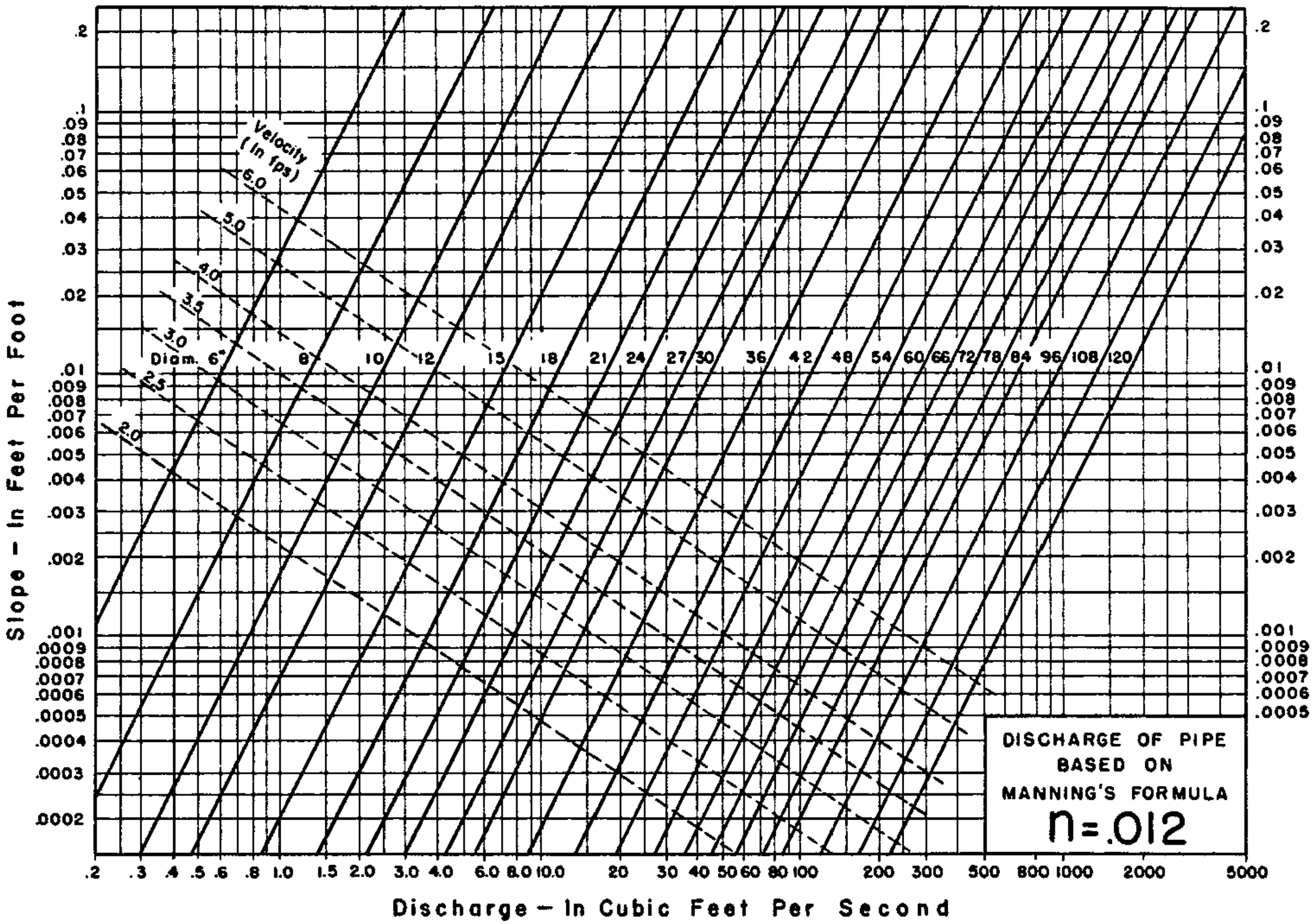

DISCHARGE OF PIPE
BASED ON
MANNING'S FORMULA
n=.012
Slope – In Feet Per Foot
Discharge – In Cubic Feet Per Second
Velocity (In fps)
6.0
5.0
4.0
3.5
3.0
2.5
2.0
Diam. 6"
8
10
12
15
18
21
24
27
30
36
42
48
54
60
66
72
78
84
96
108
120
.2 .1 .09 .08 .07 .06 .05 .04 .03 .02 .01 .009 .008 .007 .006 .005 .004 .003 .002 .001 .0009 .0008 .0007 .0006 .0005 .0004 .0003 .0002
.2 .3 .4 .5 .6 .8 1.0 1.5 2.0 3.0 4.0 6.0 8.0 10.0 20 30 40 50 60 80 100 200 300 500 800 1000 2000 5000

Figure 3

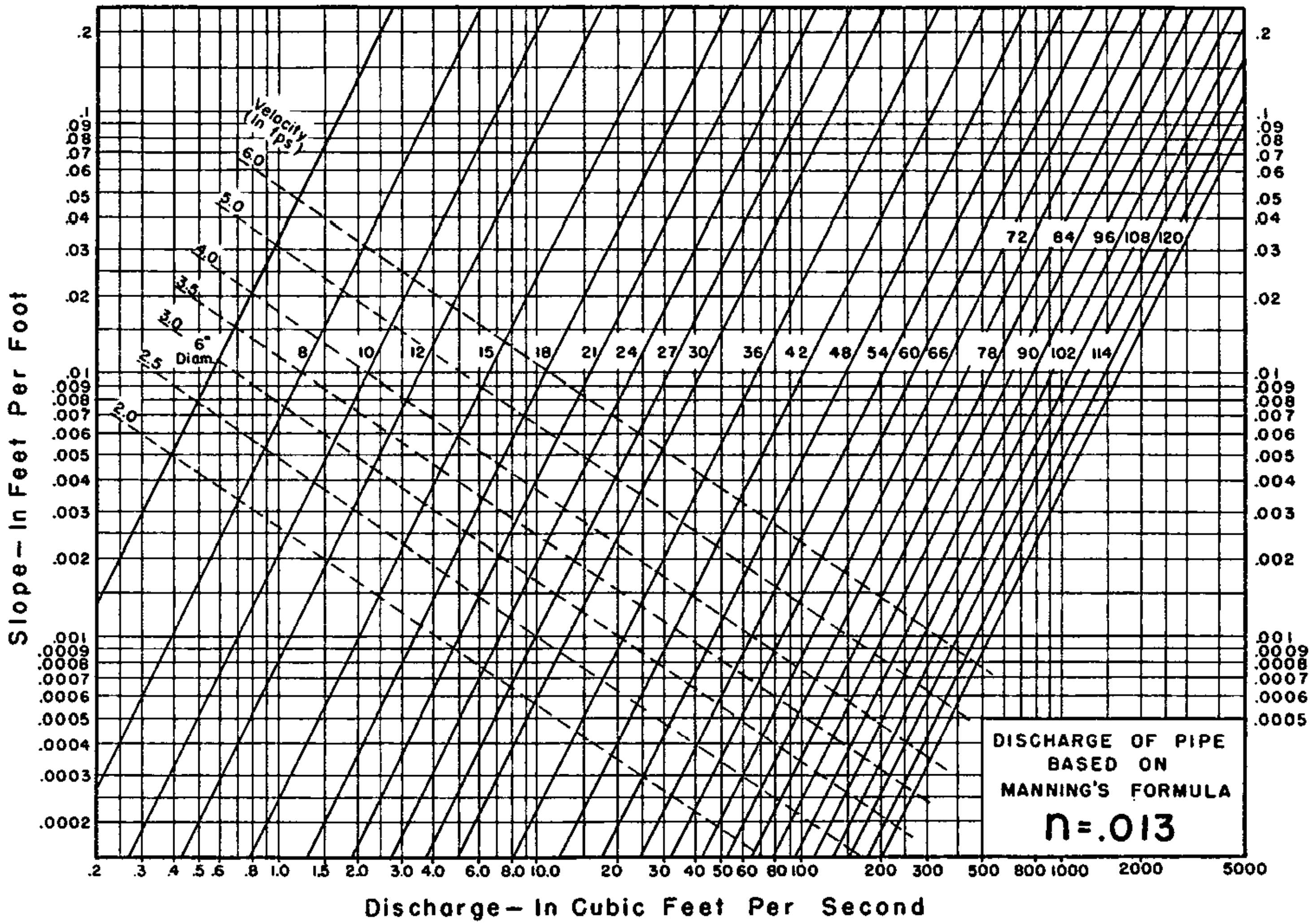

Slope— In Feet Per Foot
Discharge— In Cubic Feet Per Second
Velocity (in fps)
6.0
5.0
4.0
3.5
3.0
2.5
2.0
6" Diam.
8
10
12
15
18
21
24
27
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
DISCHARGE OF PIPE
BASED ON
MANNING'S FORMULA
n=.013

Figure 4

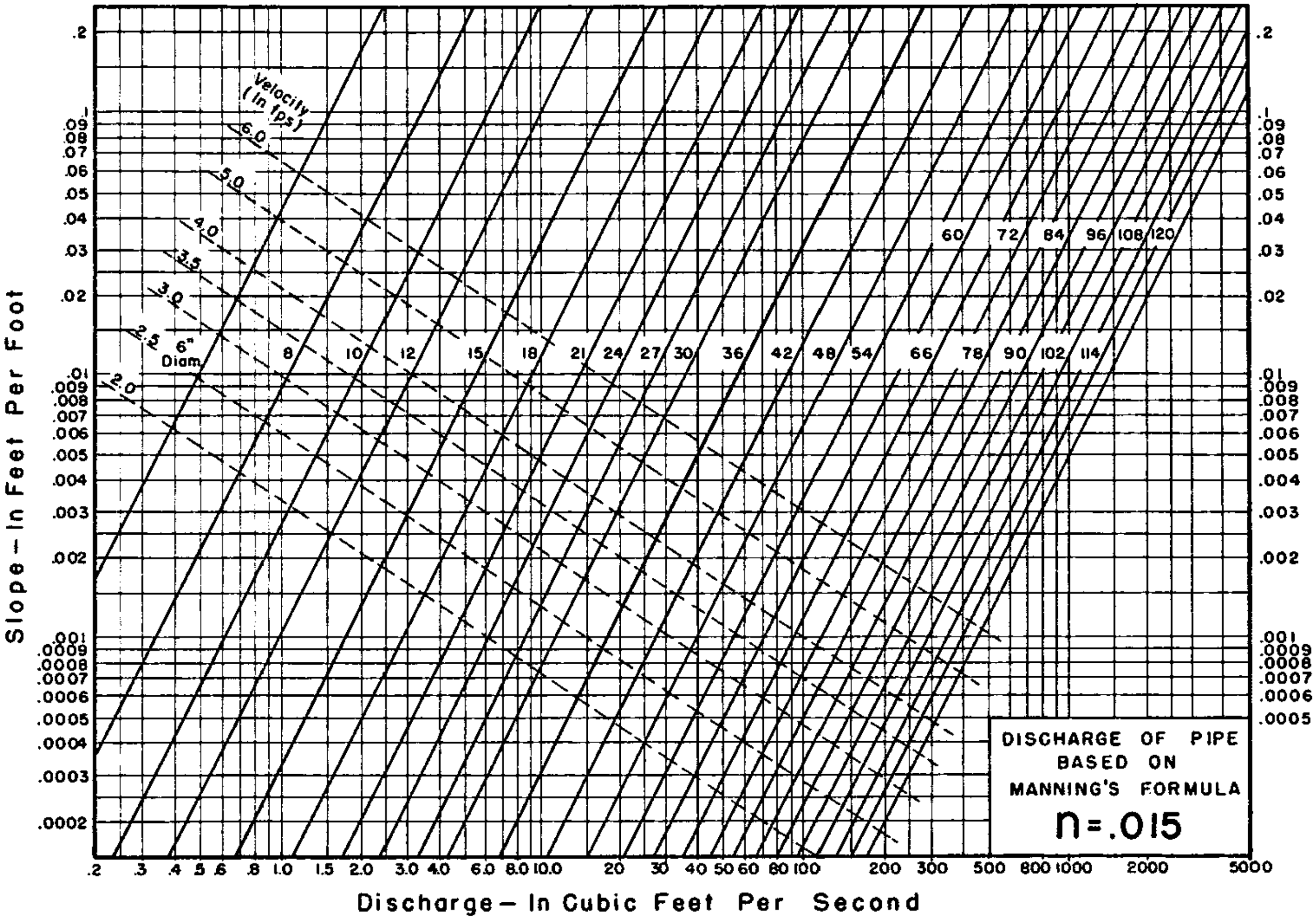
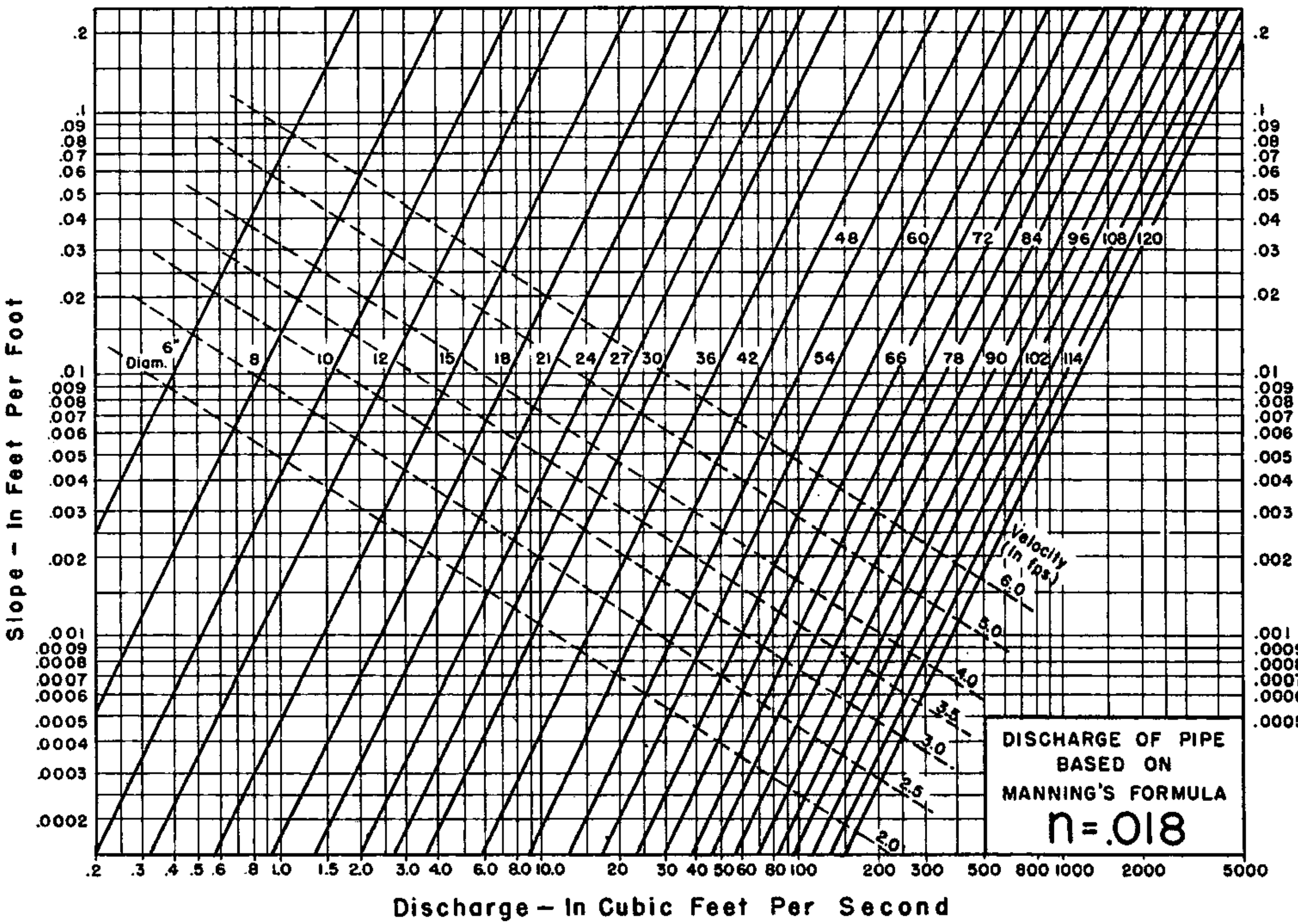

DISCHARGE OF PIPE
BASED ON
MANNING'S FORMULA
n=.015
Slope - In Feet Per Foot
Discharge - In Cubic Feet Per Second
Velocity (In fps)
6.0
5.0
4.0
3.5
3.0
2.5
2.0
6" Diam.
8
10
12
15
18
21
24
27
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.2 .3 .4 .5 .6 .8 1.0 1.5 2.0 3.0 4.0 6.0 8.0 10.0 20 30 40 50 60 80 100 200 300 500 800 1000 2000 5000

Figure 5



DISCHARGE OF PIPE BASED ON MANNING'S FORMULA
n=.018
Slope - In Feet Per Foot
Discharge - In Cubic Feet Per Second
6" Diam.
8
10
12
15
18
21
24
27
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
Velocity (In fps.)
6.0
5.0
4.0
3.5
3.0
2.5
2.0
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.2 .3 .4 .5 .6 .8 1.0 1.5 2.0 3.0 4.0 6.0 8.0 10.0 20 30 40 50 60 80 100 200 300 500 800 1000 2000 5000

Figure 6

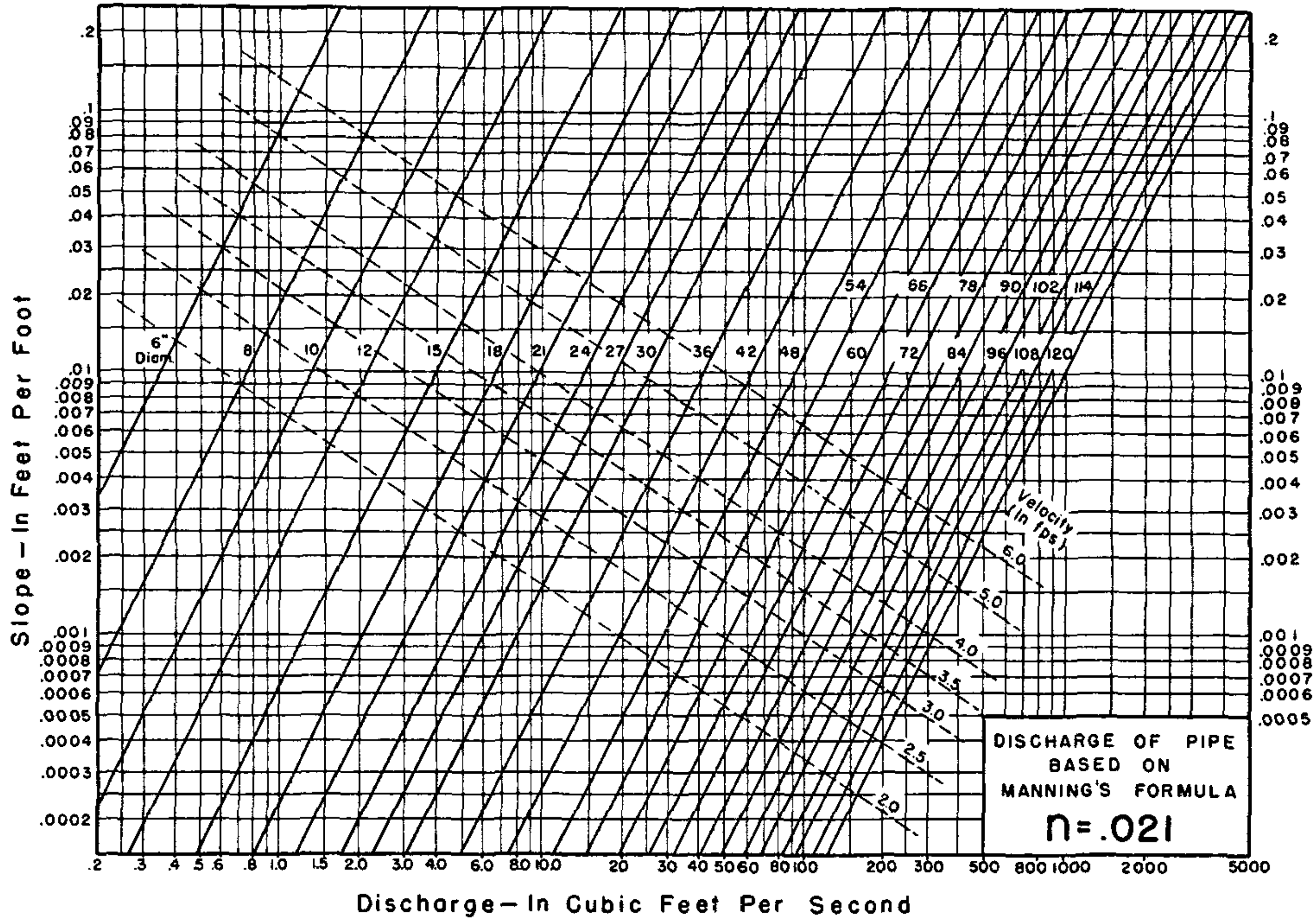

DISCHARGE OF PIPE
BASED ON
MANNING'S FORMULA
n=.021
Slope – In Feet Per Foot
Discharge – In Cubic Feet Per Second
Velocity (in fps)
6" Diam.
8
10
12
15
18
21
24
27
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
6.0
5.0
4.0
3.5
3.0
2.5
2.0

Figure 7

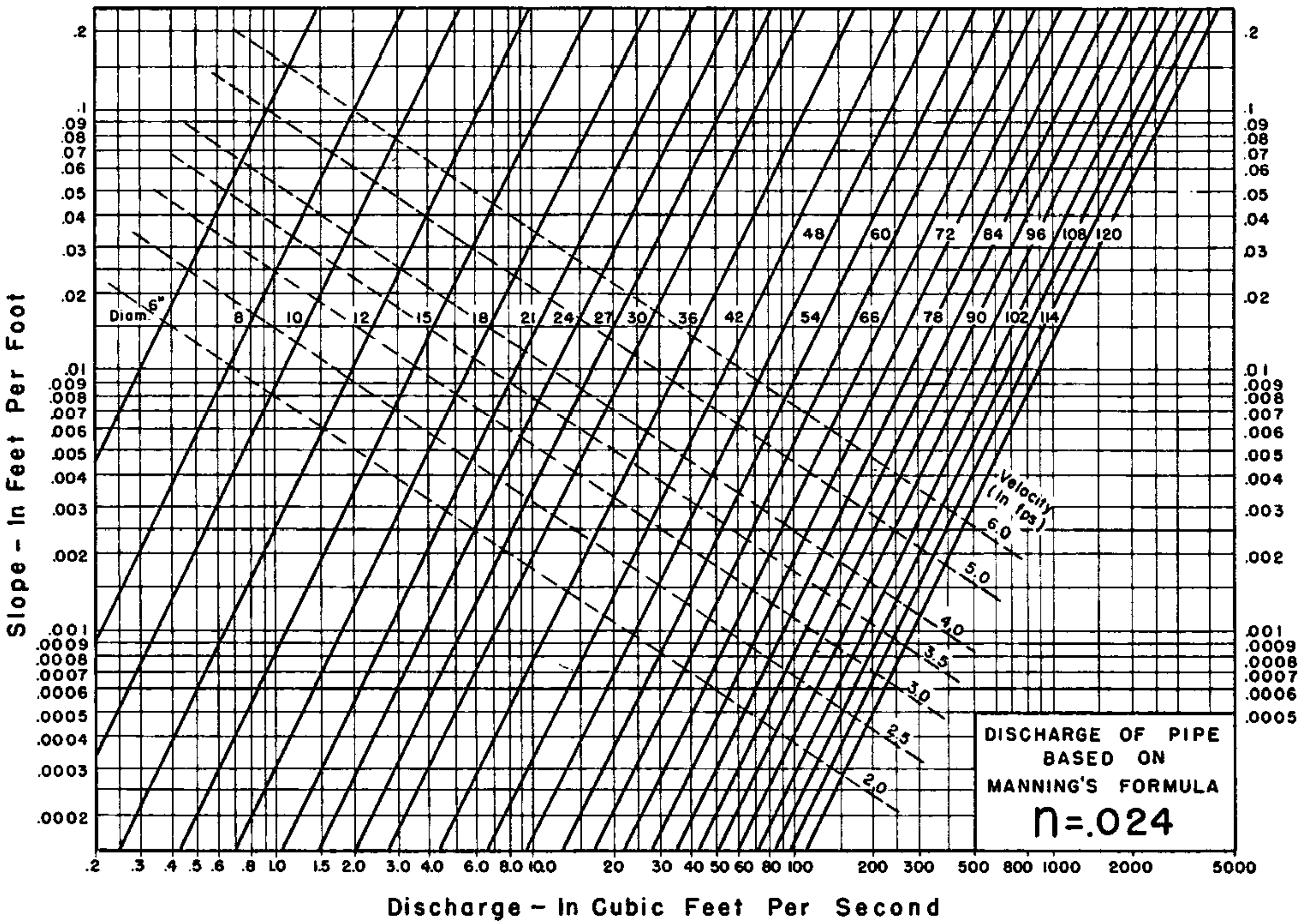
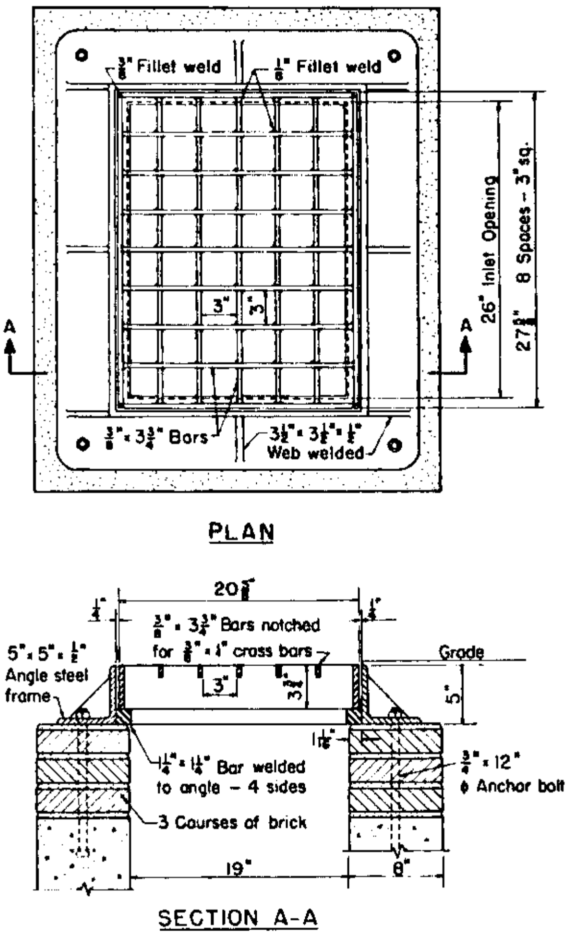
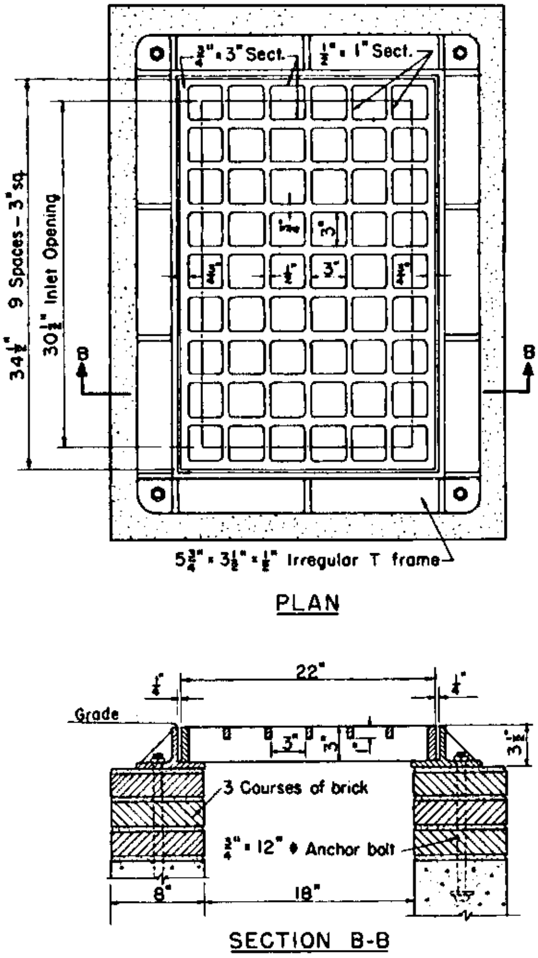

DISCHARGE OF PIPE
BASED ON
MANNING'S FORMULA
n=.024
Slope - In Feet Per Foot
Discharge - In Cubic Feet Per Second
Diam. 6"
8
10
12
15
18
21
24
27
30
36
42
48
54
60
66
72
78
84
90
96
102
108
114
120
Velocity (In fps)
6.0
5.0
4.0
3.5
3.0
2.5
2.0
.2
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0009
.0008
.0007
.0006
.0005
.0004
.0003
.0002
.2 .3 .4 .5 .6 .8 1.0 1.5 2.0 3.0 4.0 6.0 8.0 10.0 20 30 40 50 60 80 100 200 300 500 800 1000 2000 5000

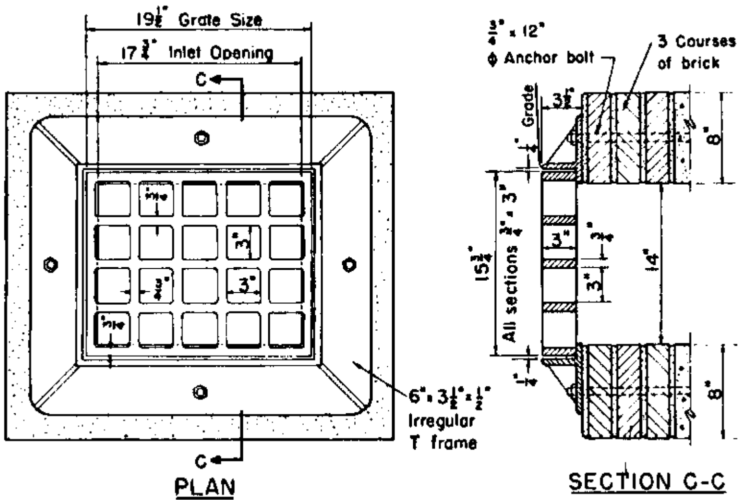
Figure 8



Welded Steel Grate ①



Cast Wrought Iron Grate ②

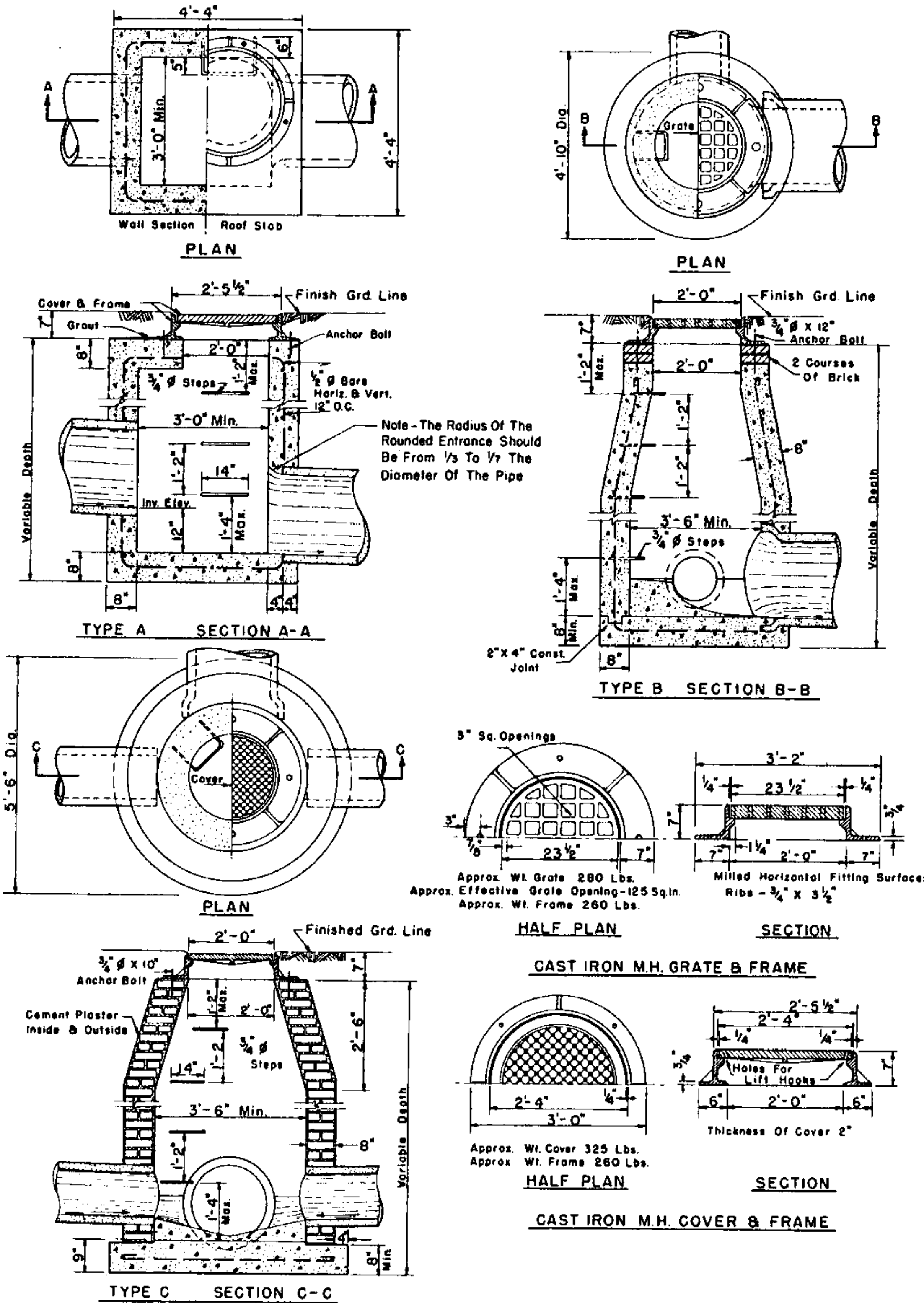


Cast Iron Inlet Grate ③

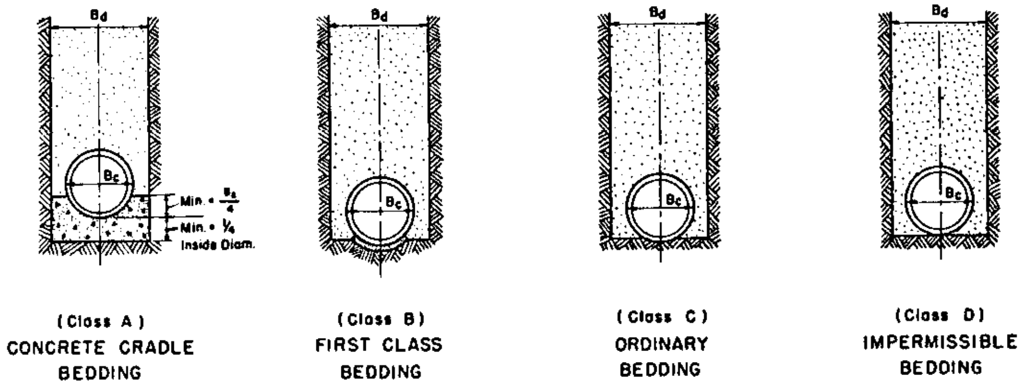
NOTES:

1. Inlet grating and frame to withstand aircraft wheel loads of largest aircraft to use the facility.
2. Weight of grate (Approximate)
   Grate No. 1 – 150 lbs.
   Grate No. 2 – 205 lbs.
   Grate No. 3 – 115 lbs.
3. Effective grate openings
   Grate No. 1 – 432 sq. in.
   Grate No. 2 – 486 sq. in.
   Grate No. 3 – 180 sq. in.
4. Frames may be made larger when necessary to accomodate two or more of the grates.
5. Furnish tiedowns for grates, as required.

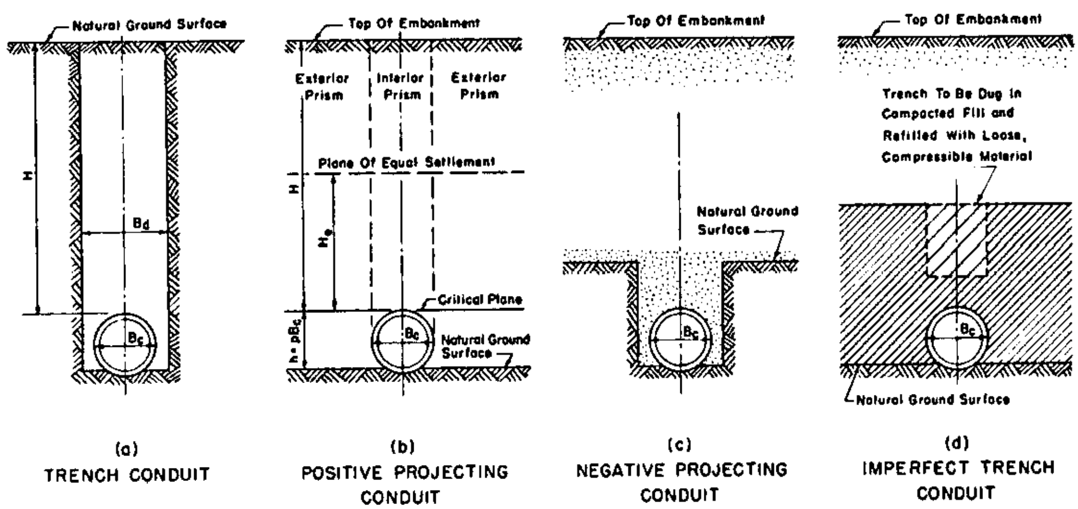
Examples Of Typical Inlet Grates
Figure 9



Suggested Manhole Design
Figure 12

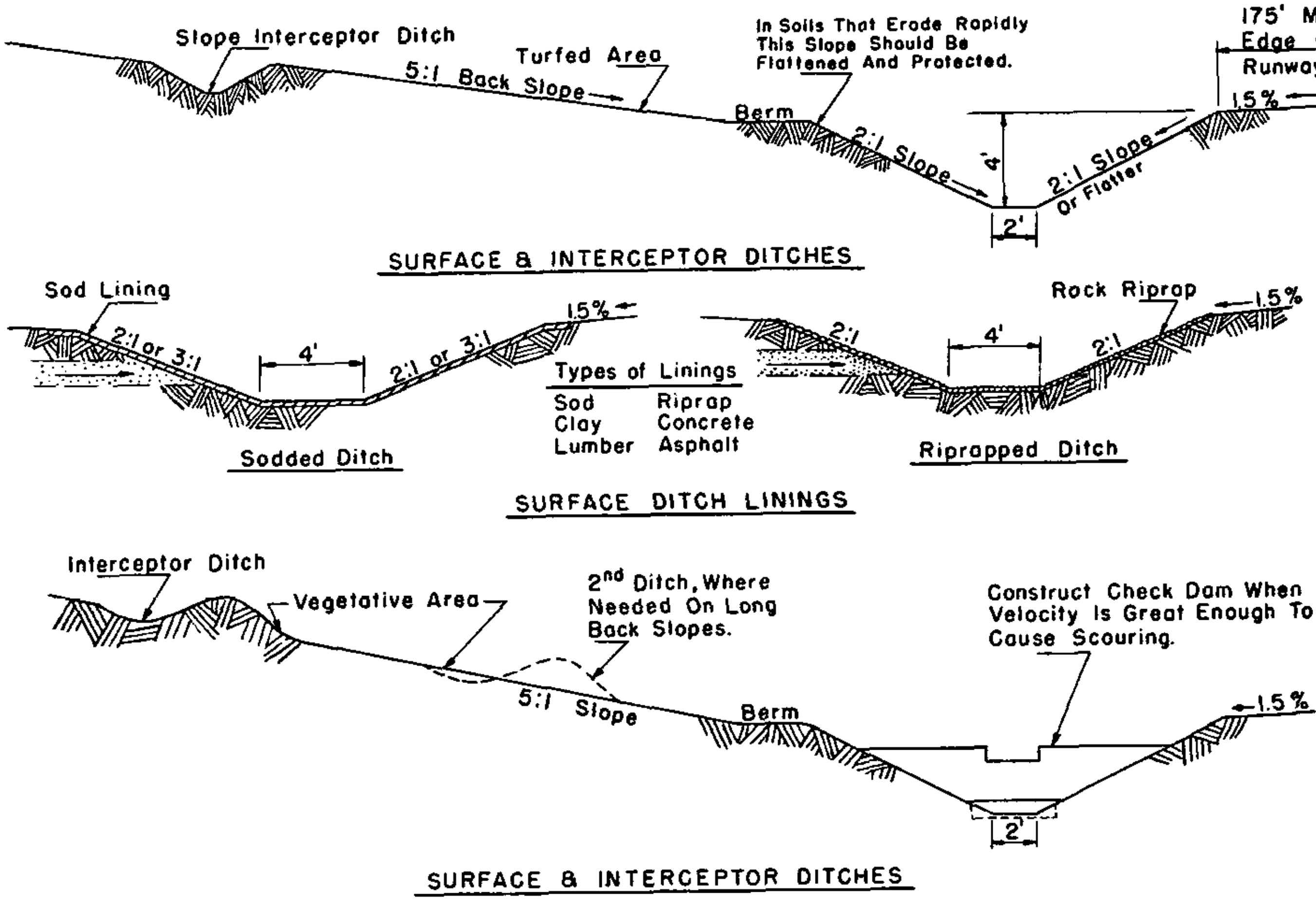


Trench Conduit Beddings

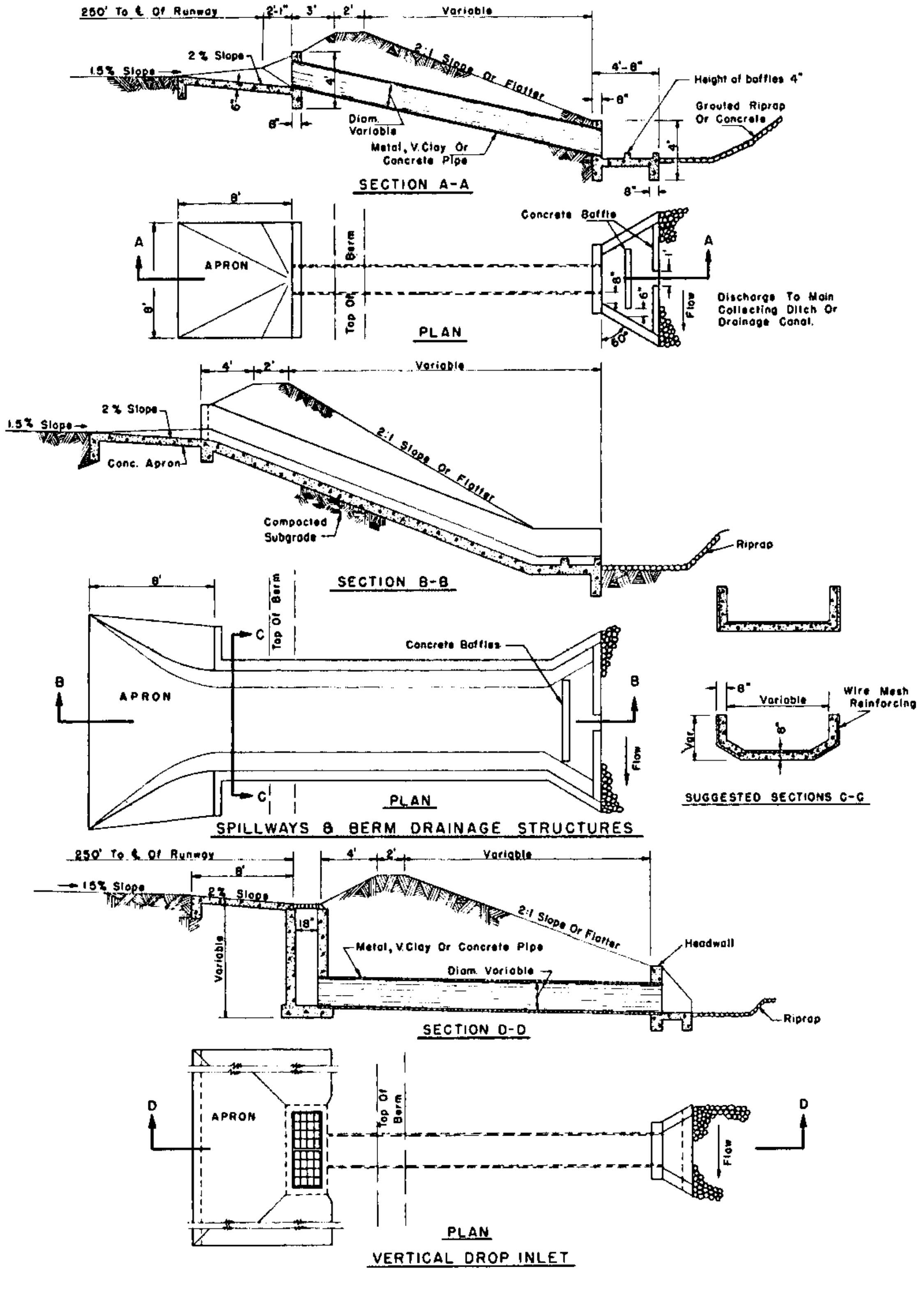


Trench And Projecting Conduits

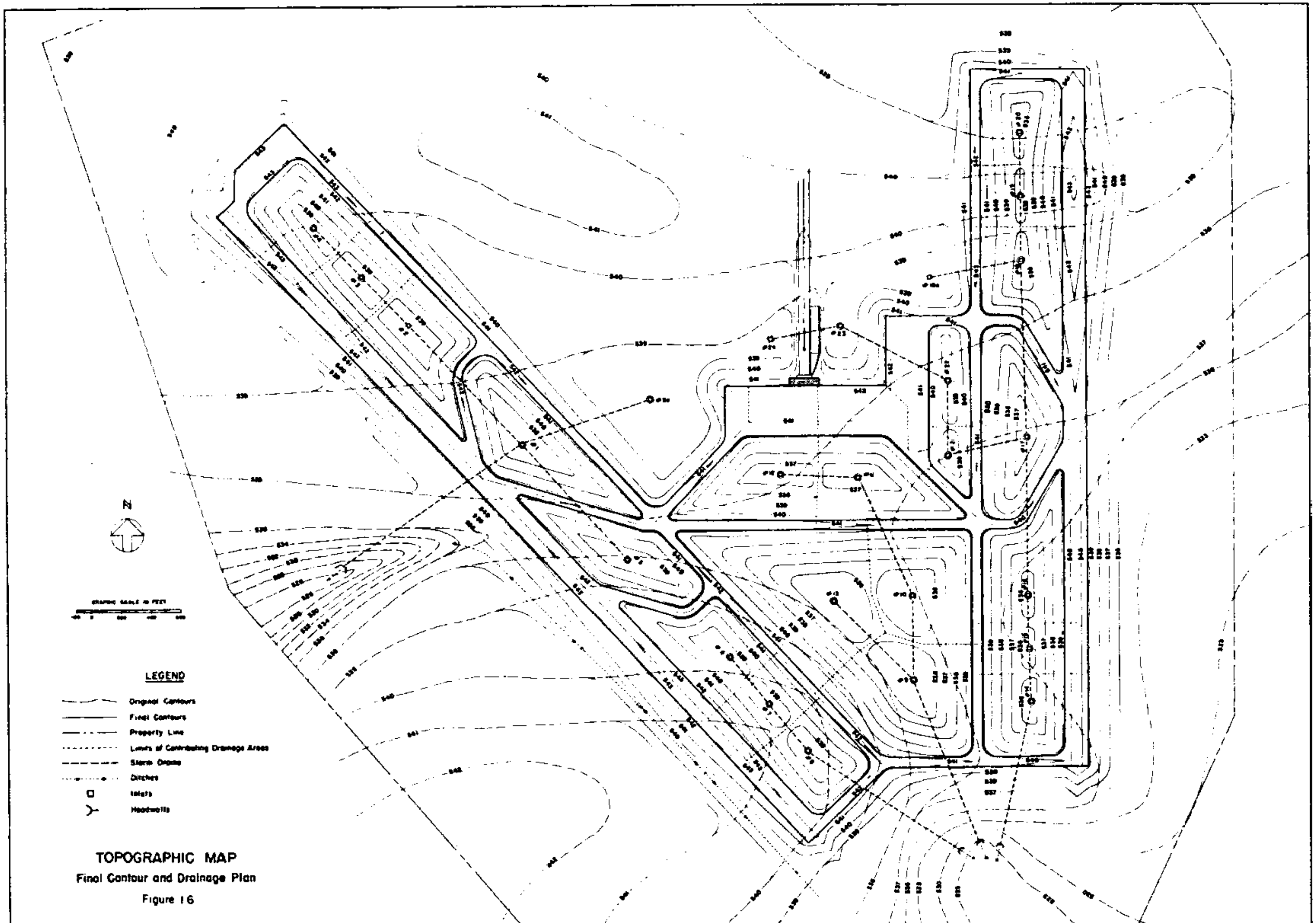
Figure 13



Types Of Surface And Interceptor Ditches
Figure 14

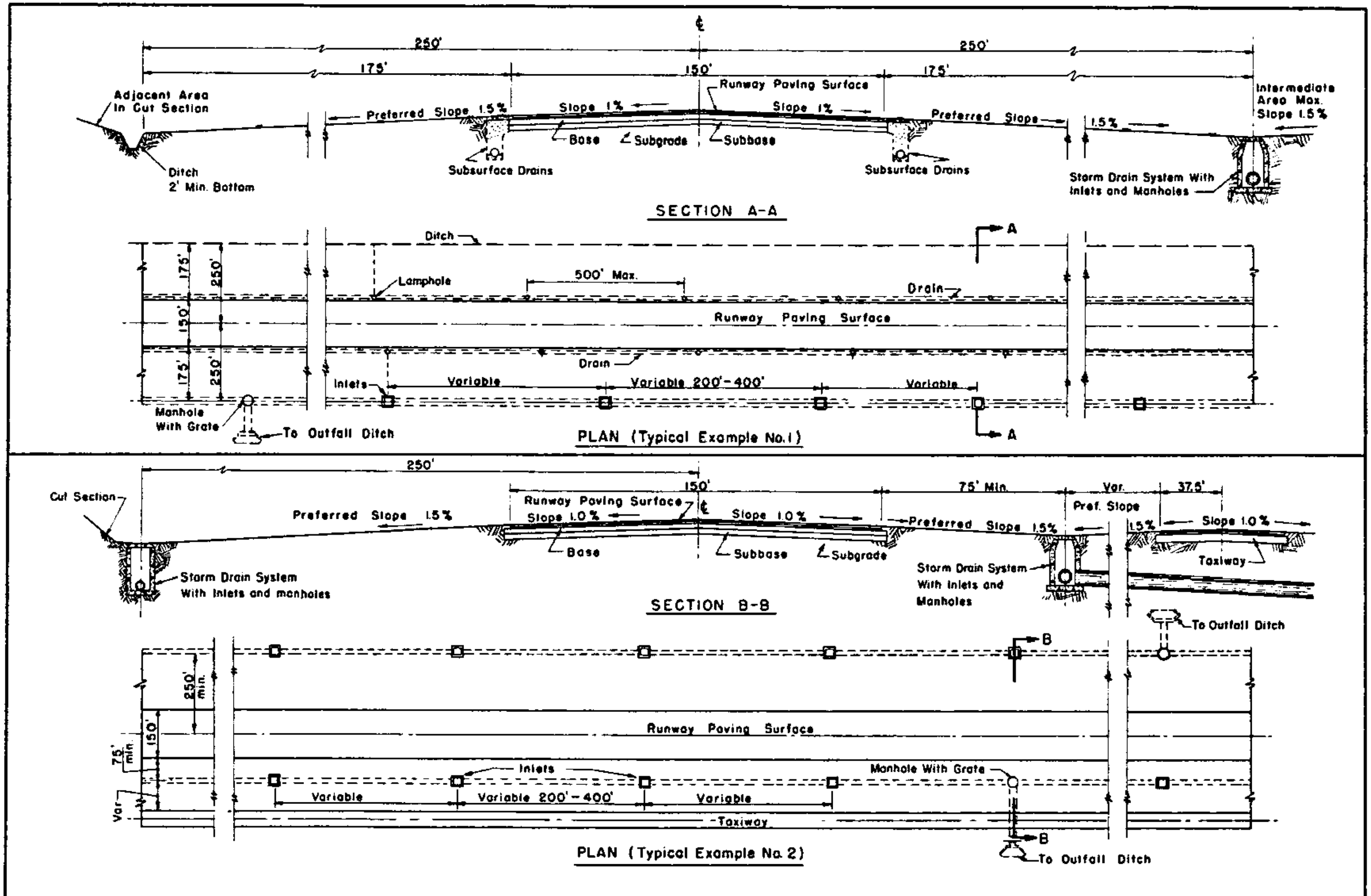


Typical Embankment Protection Structures
Figure 15

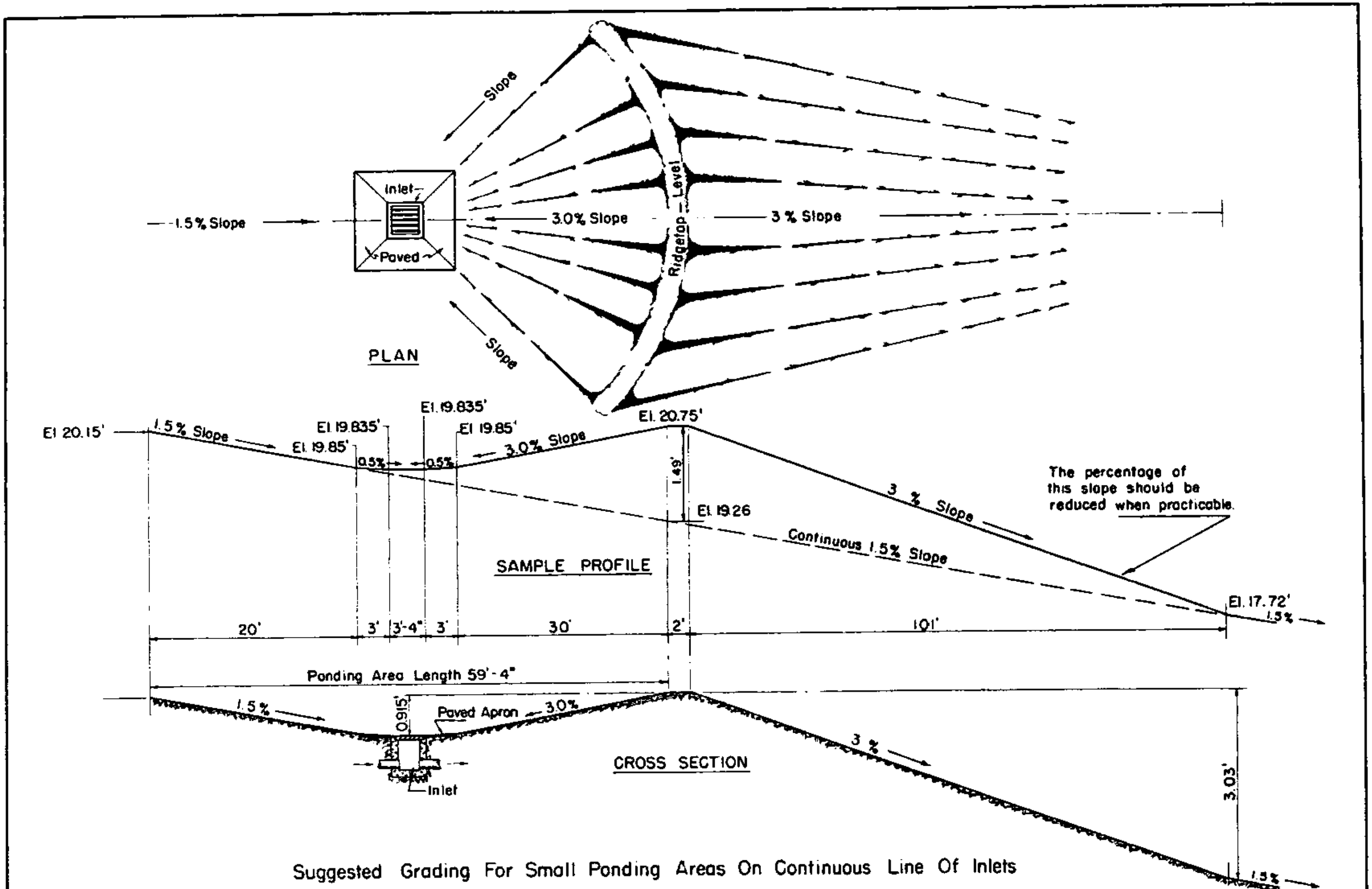


TOPOGRAPHIC MAP
Final Contour and Drainage Plan
Figure 16

785-580 O - 68 - 4



Typical Landing Strip And Runway Drainage
Figure 17



Suggested Grading For Small Ponding Areas On Continuous Line Of Inlets

Figure 18

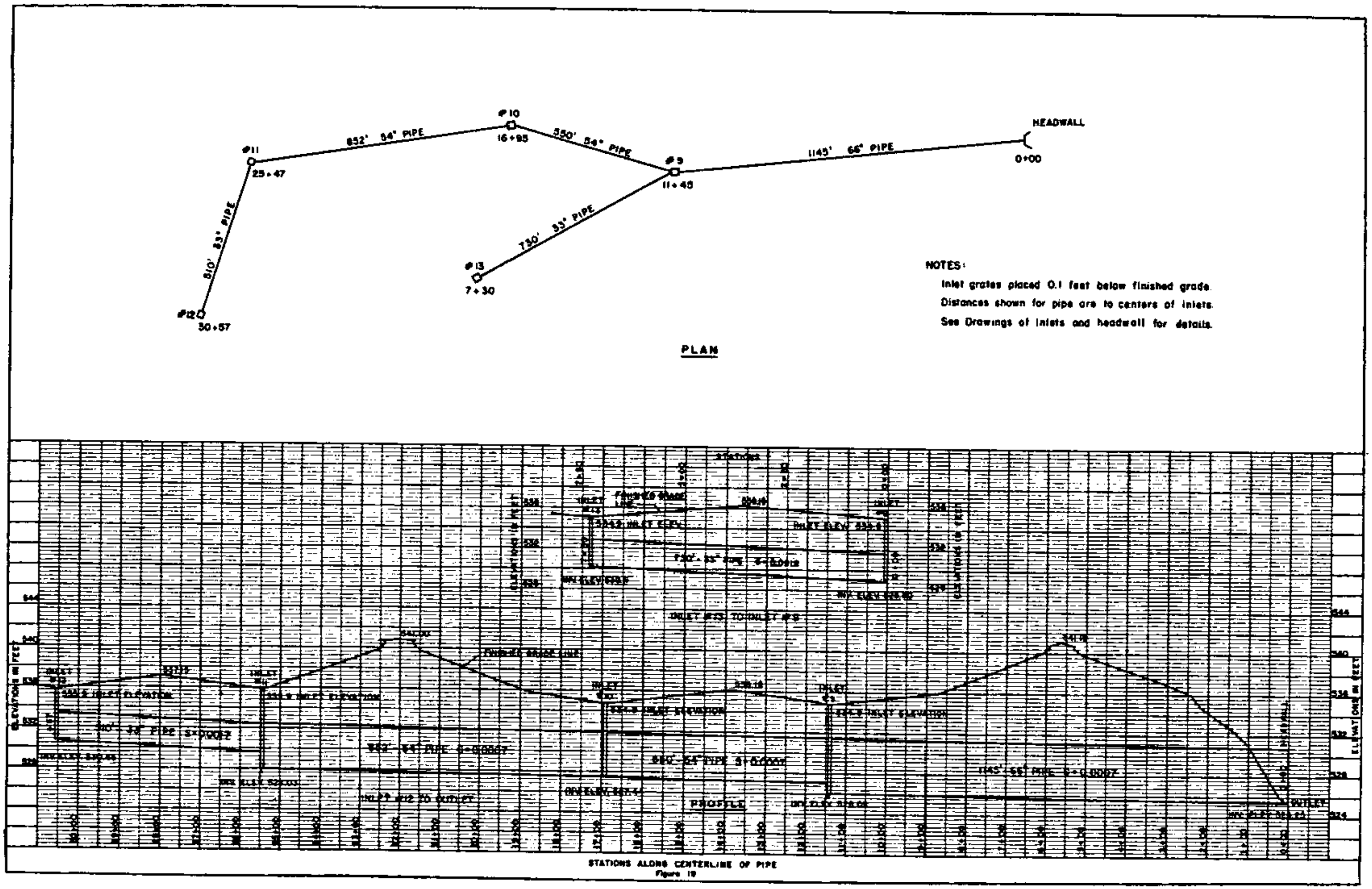
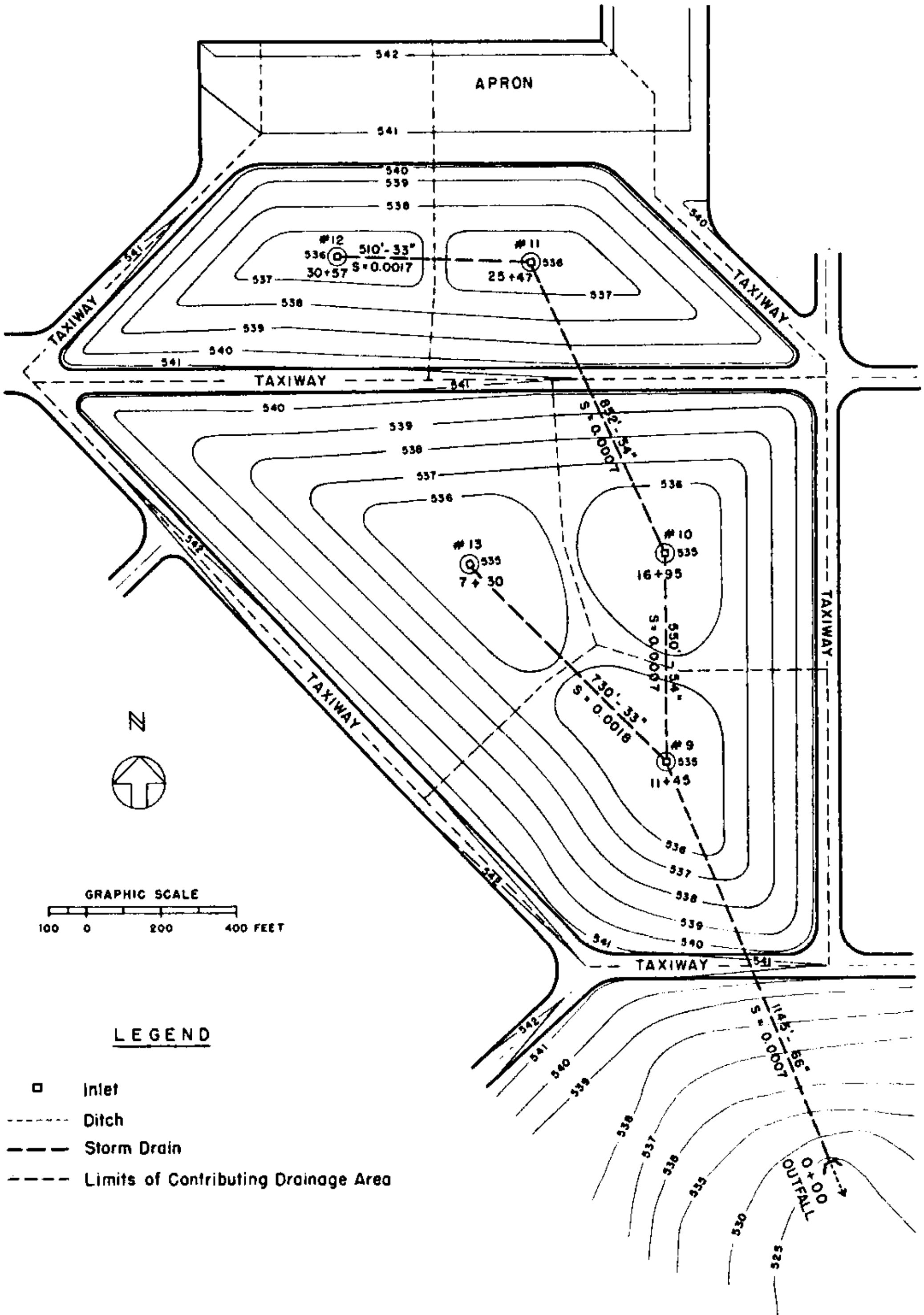
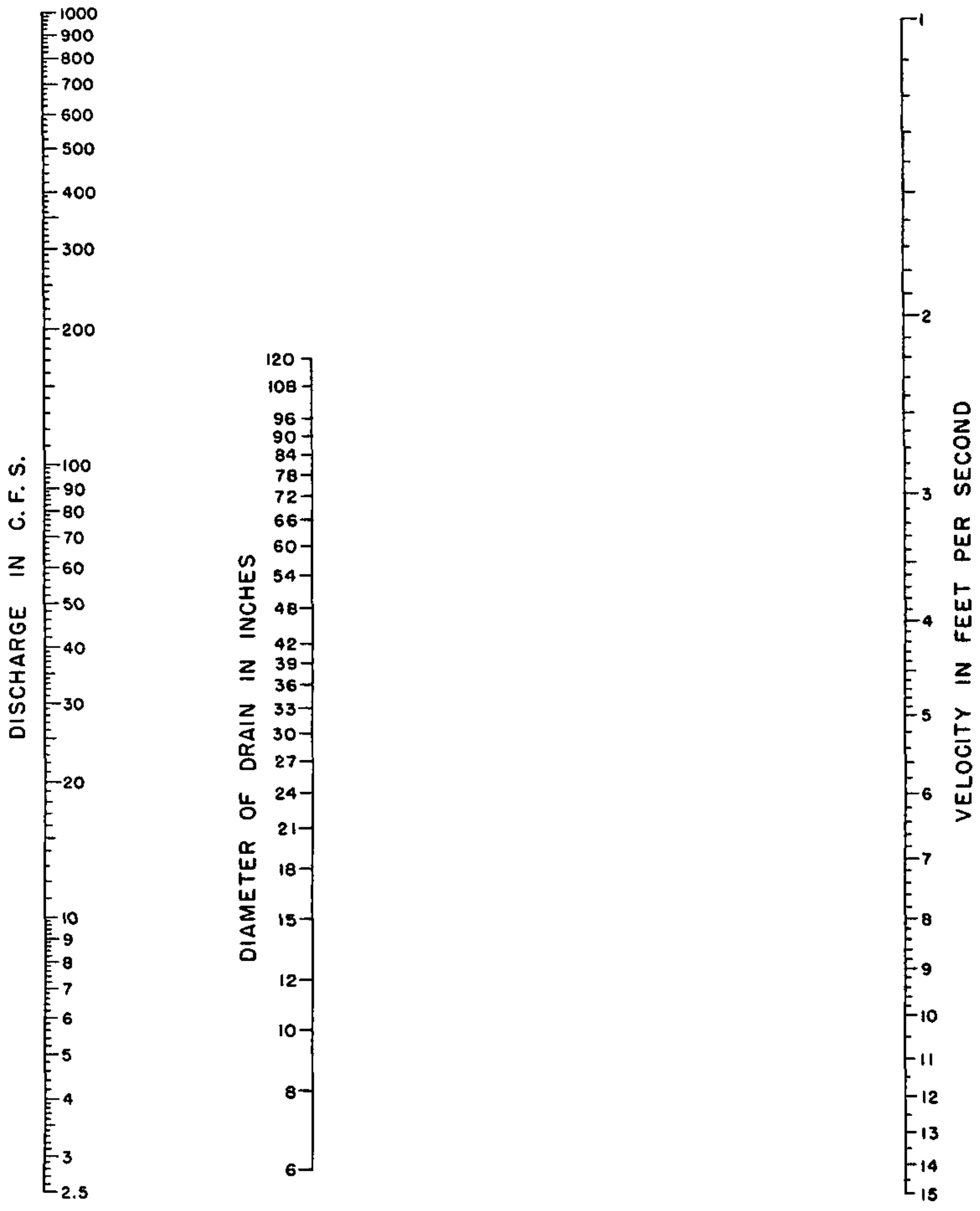

#10
16+95
852' 54" PIPE
550' 54" PIPE
#11
25+47
#9
11+45
1145' 66" PIPE
HEADWALL
0+00
510' 33" PIPE
730' 33" PIPE
#13
7+30
#12
30+57
NOTES:
Inlet grates placed 0.1 feet below finished grade.
Distances shown for pipe are to centers of inlets.
See Drawings of inlets and headwall for details.
PLAN
STATIONS
INLET #13 TO INLET #9
FINISHED GRADE LINE
PROFILE
STATIONS ALONG CENTERLINE OF PIPE

Figure 19



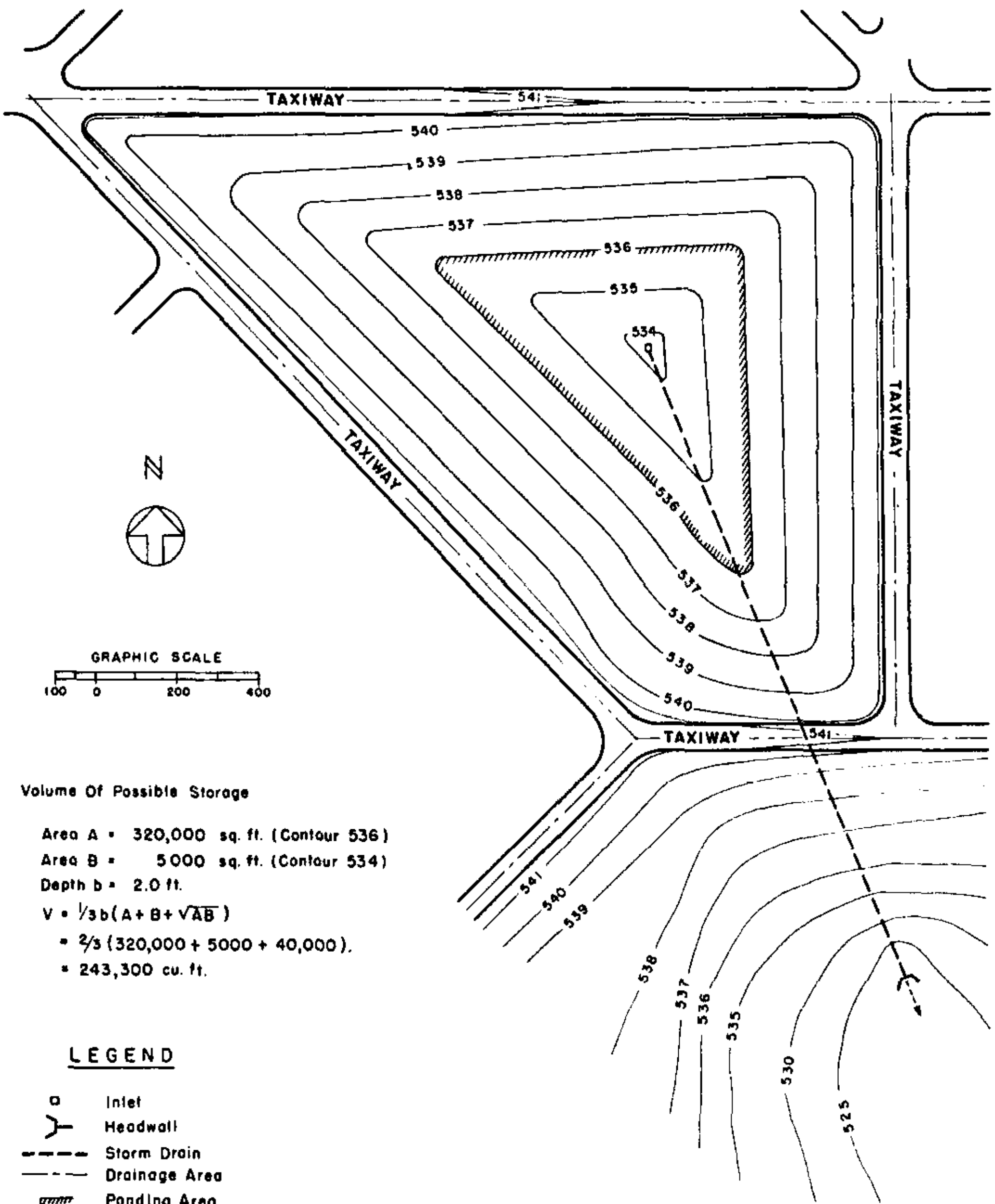
Portion of airport showing drainage design

Figure 20



Nomograph for determining velocity of circular drain, flowing full

Figure 21



Volume Of Possible Storage

Area A = 320,000 sq. ft. (Contour 536)
Area B = 5000 sq. ft. (Contour 534)
Depth b = 2.0 ft.

$V = \frac{1}{3} b (A + B + \sqrt{AB})$

$= \frac{2}{3} (320{,}000 + 5000 + 40{,}000)$

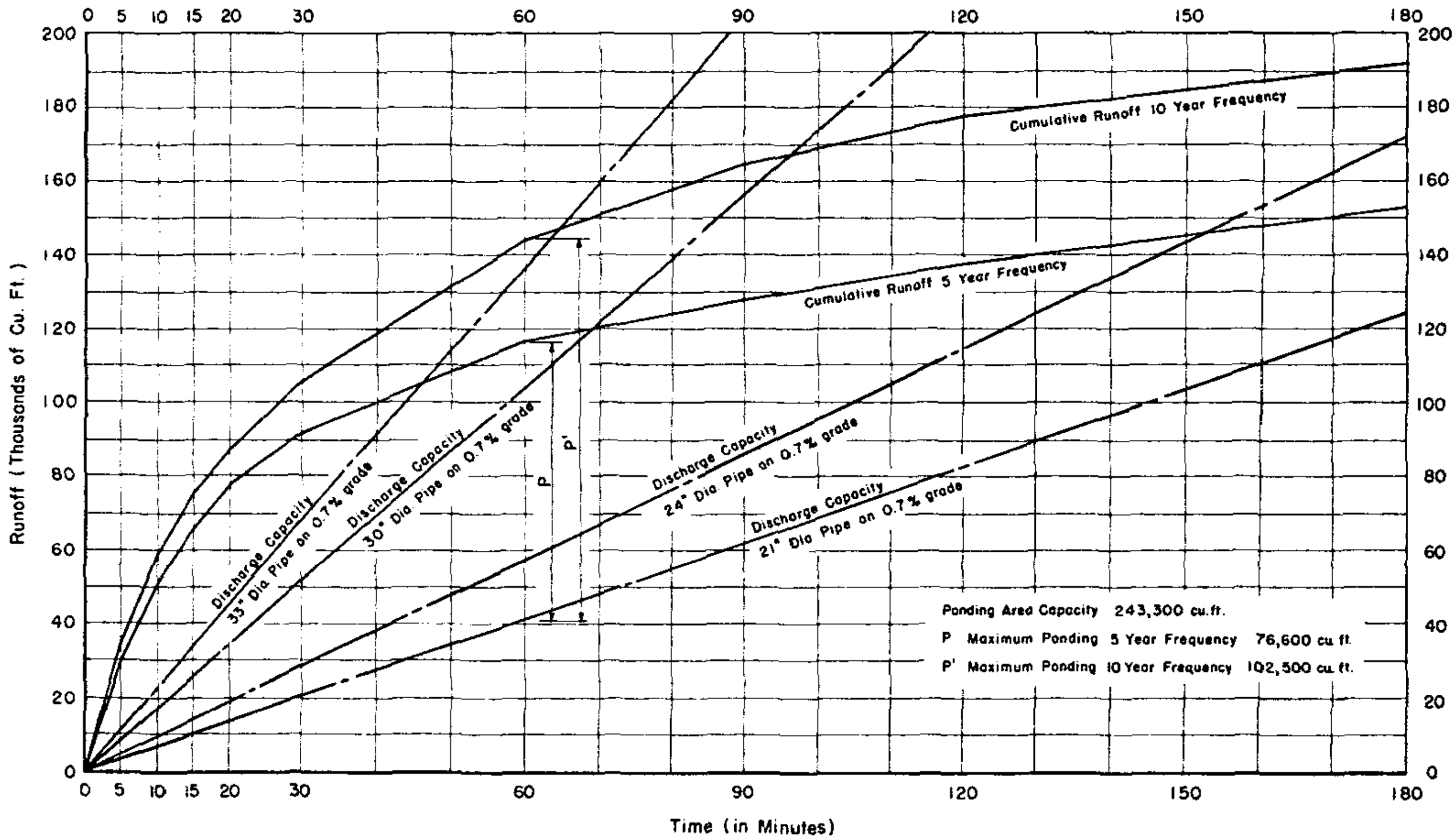
$= 243{,}300$ cu. ft.

LEGEND

- ▫ Inlet
- Headwall
- Storm Drain
- Drainage Area
- Ponding Area

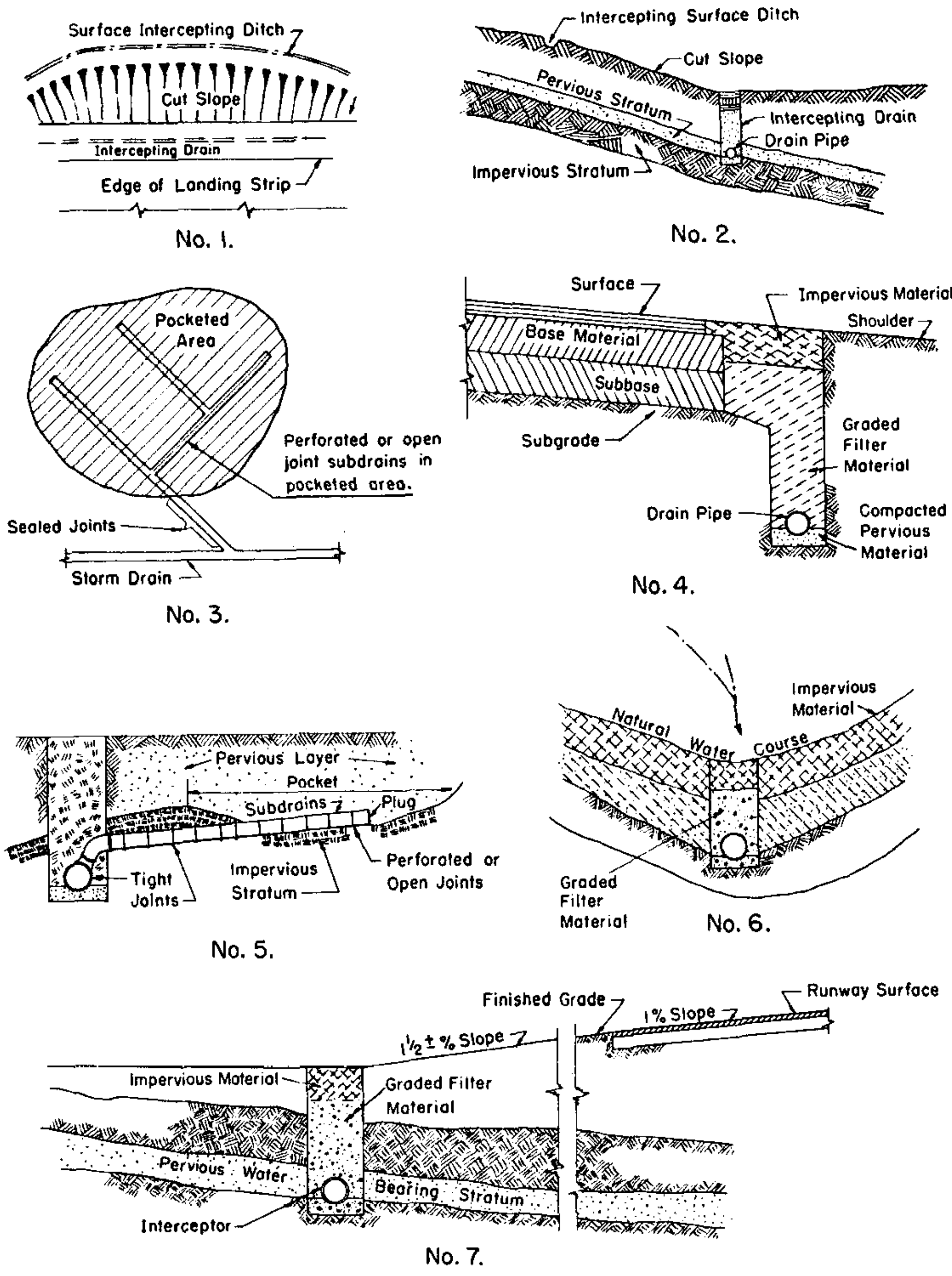
Example Of Providing For Ponding Area

Figure 22



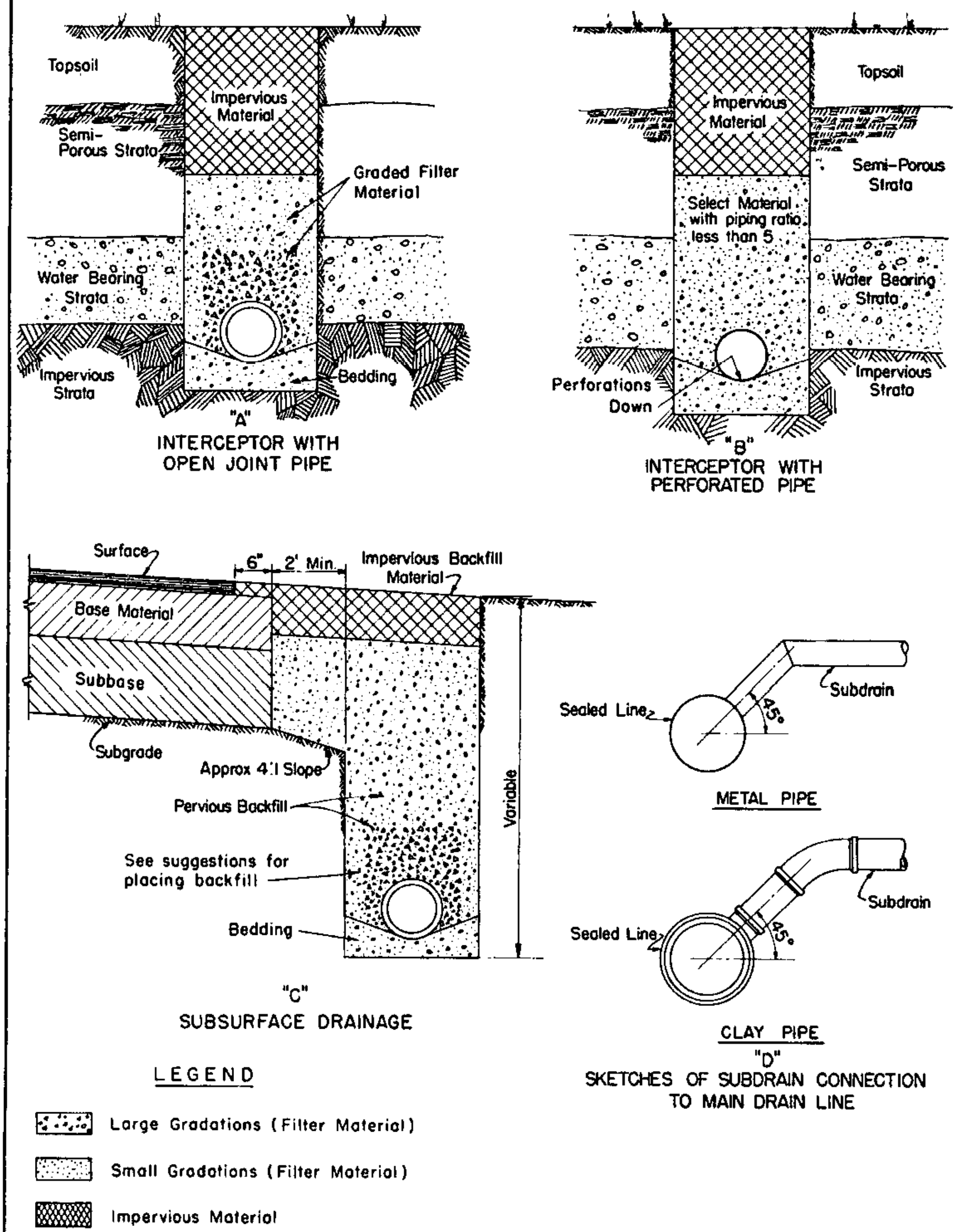
Cumulative runoff for ponding in Figure No. 22

Figure 23



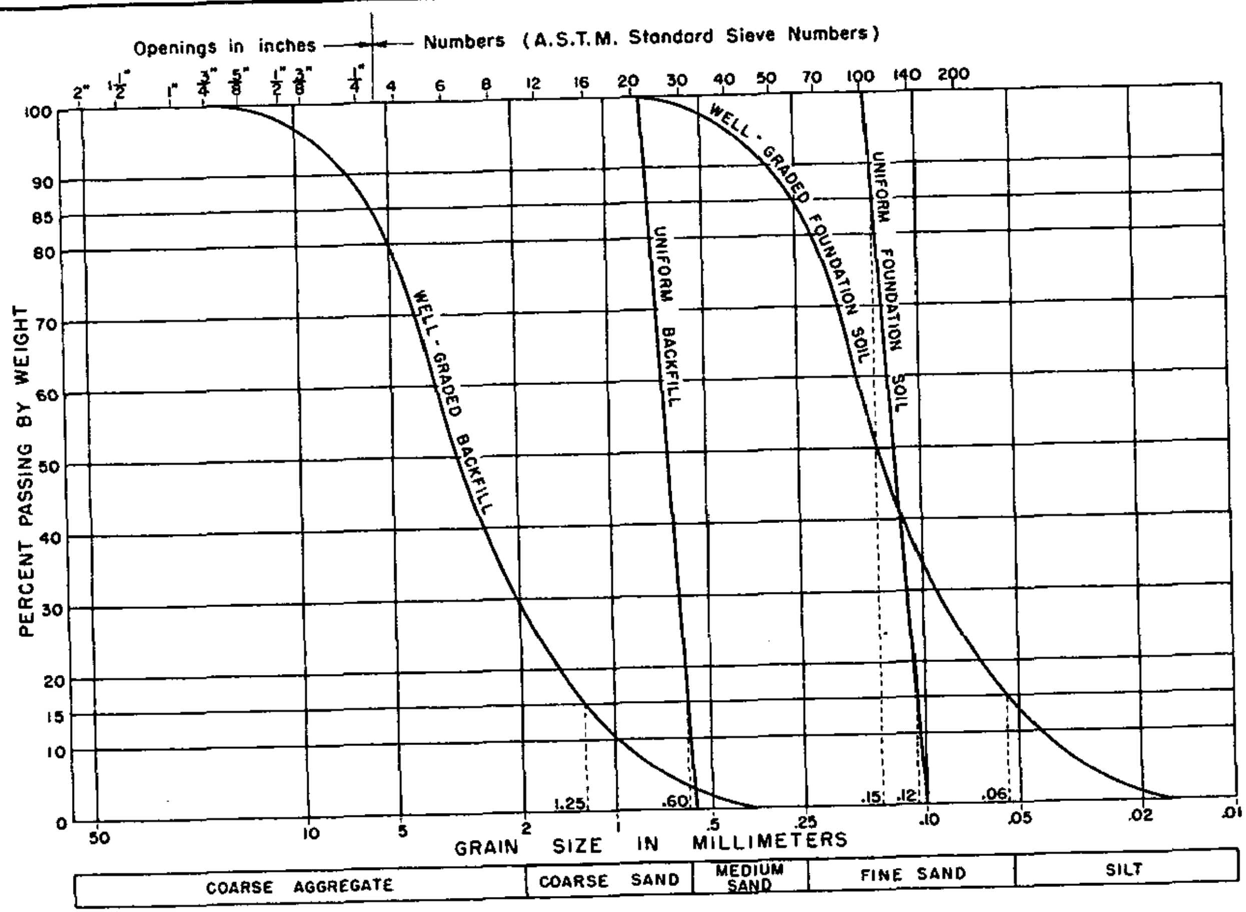
Types of subsurface drainage.

Figure 24



Typical section of subsurface drains

Figure 25



PIPING RATIO:

$\frac{\text{15\% SIZE UNIFORM BACKFILL}}{\text{85\% SIZE UNIFORM FOUNDATION}}$, NOT GREATER THAN 4.0

$\frac{\text{15\% SIZE WELL GRADED BACKFILL}}{\text{85\% SIZE WELL GRADED FOUNDATION}}$, NOT GREATER THAN 5.0

PERMEABILITY RATIO:

$\frac{\text{15\% SIZE FILTER MATERIAL}}{\text{15\% SIZE FOUNDATION SOIL}}$, 5.0 OR GREATER

$\frac{\text{15\% SIZE FILTER MATERIAL}}{\text{15\% SIZE FOUNDATION SOIL}}$, NOT GREATER THAN 25

Limiting gradation for backfill surrounding pipe for subsurface drains.

Figure 26

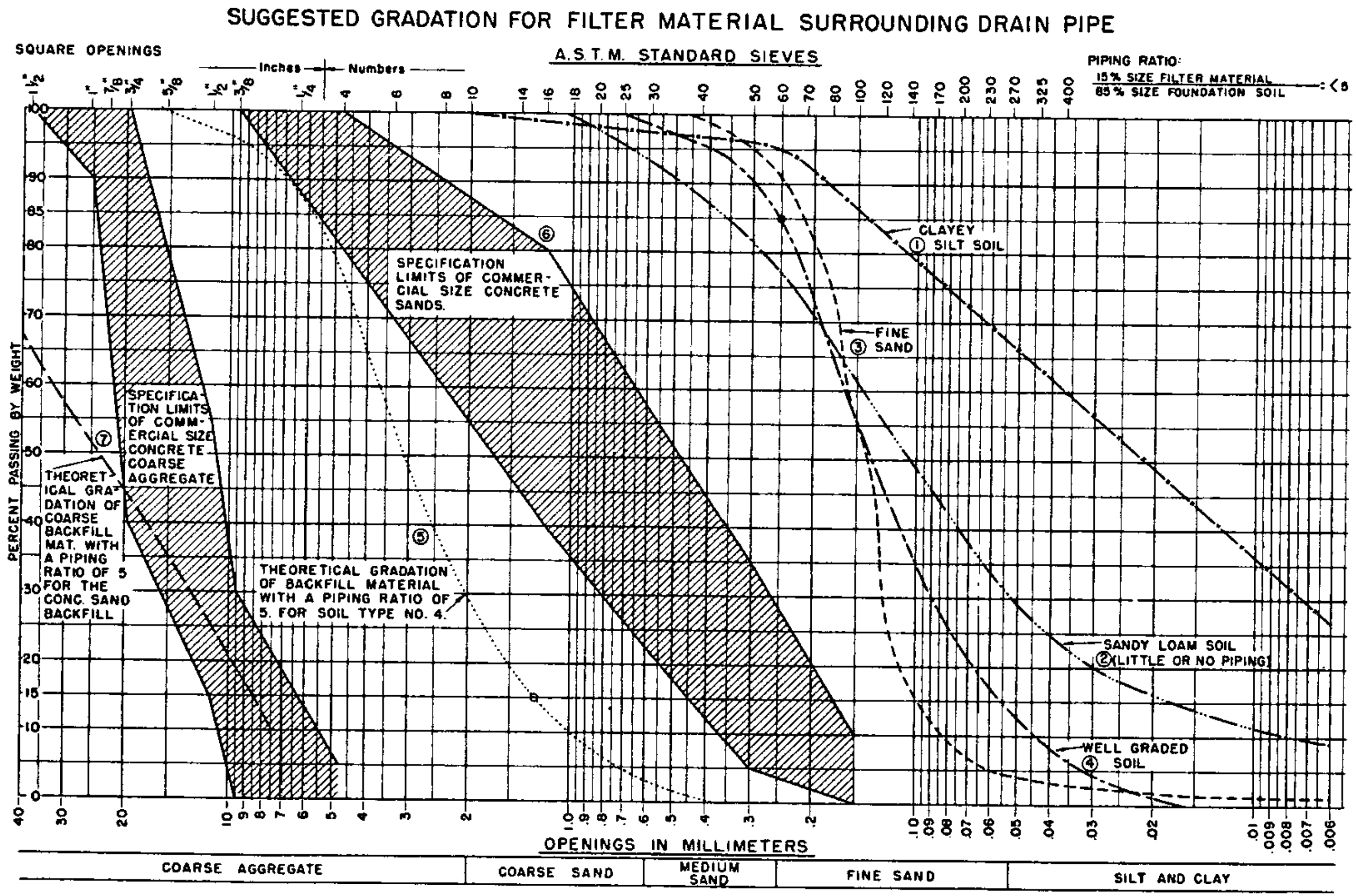
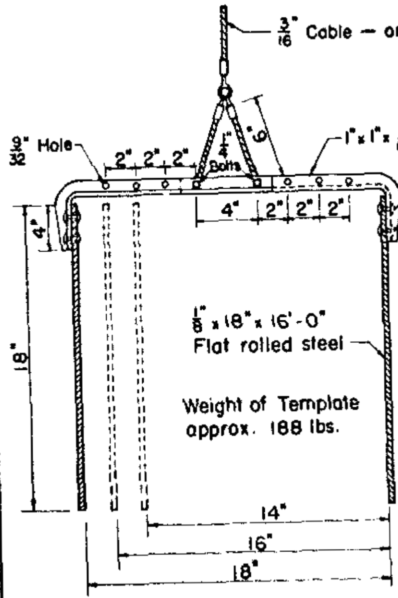
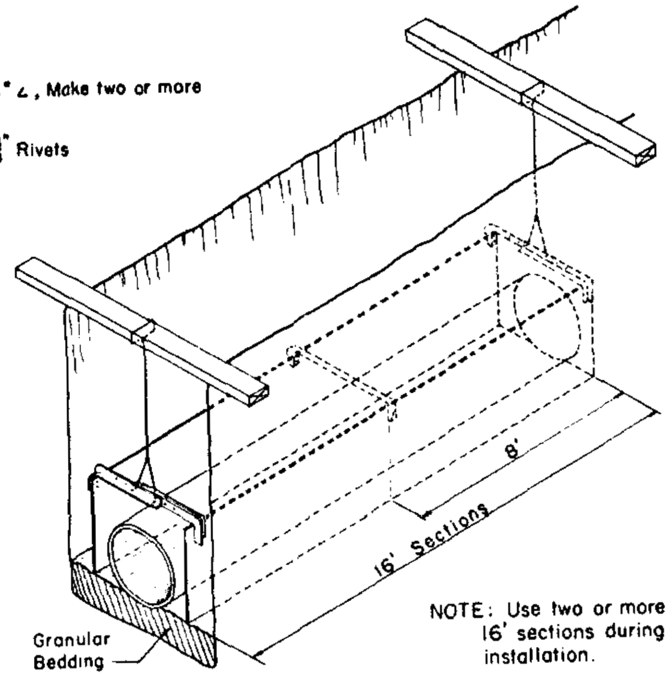

SUGGESTED GRADATION FOR FILTER MATERIAL SURROUNDING DRAIN PIPE
SQUARE OPENINGS
A.S.T.M. STANDARD SIEVES
Inches
Numbers
PIPING RATIO:
15% SIZE FILTER MATERIAL / 85% SIZE FOUNDATION SOIL : <5
PERCENT PASSING BY WEIGHT
CLAYEY ① SILT SOIL
FINE ③ SAND
SANDY LOAM SOIL ② (LITTLE OR NO PIPING)
WELL GRADED ④ SOIL
SPECIFICATION LIMITS OF COMMERCIAL SIZE CONCRETE SANDS. ⑥
SPECIFICATION LIMITS OF COMMERCIAL SIZE CONCRETE COARSE AGGREGATE
THEORETICAL GRADATION OF COARSE BACKFILL MAT. WITH A PIPING RATIO OF 5 FOR THE CONC. SAND BACKFILL ⑦
THEORETICAL GRADATION OF BACKFILL MATERIAL WITH A PIPING RATIO OF 5. FOR SOIL TYPE NO. 4. ⑤
OPENINGS IN MILLIMETERS
COARSE AGGREGATE
COARSE SAND
MEDIUM SAND
FINE SAND
SILT AND CLAY

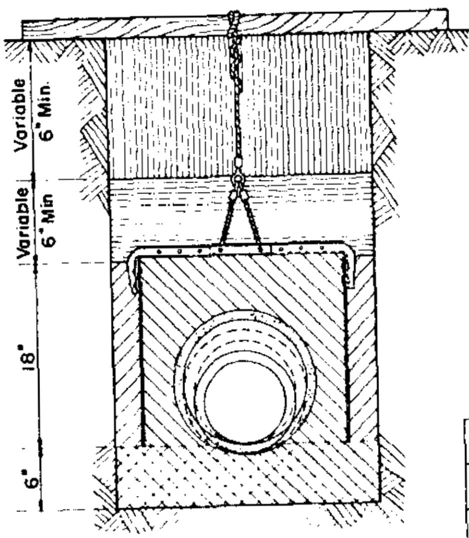
Figure 27



TEMPLATE



ISOMETRIC VIEW OF PIPE AND TEMPLATE IN TRENCH



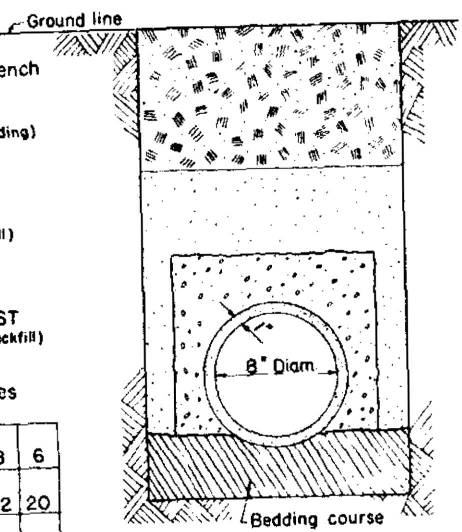
Order of Filling Trench

- PLACE 1st (Granular Bedding)
- PLACE 2nd (Fine Backfill)
- PLACE 3rd (Coarse Backfill)
- PLACE 4th (Fine Backfill)
- PLACE LAST (Impervious Backfill)

Sizes in Inches

Diameter	10	8	6
Width of Trench	24	22	20
Width of Template	18	16	14

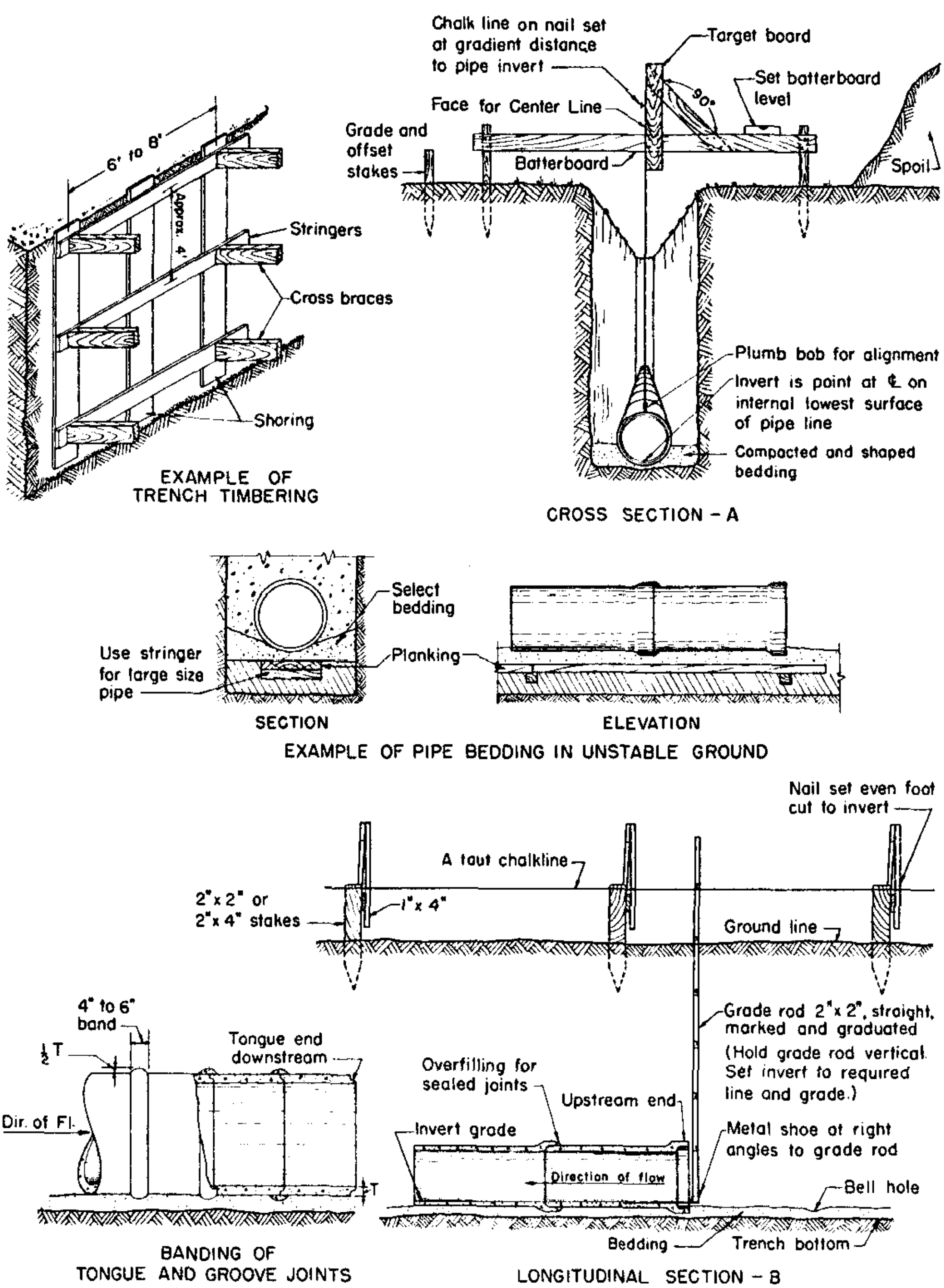
TRENCH
(Template In Place)



TRENCH BACKFILL
(Template Removed)

Template And Trench Width For Two Gradation Pervious Backfill

Figure 28



Methods Of Laying Drainage Pipe

Figure 29

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