Chapter 5. THE DRAINAGE SYSTEM

17. 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. Rainfall 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. A frequency curve for 10 years should also be plotted for checking excess storms and verifying ponding capacity. A 2-year curve will illustrate intensity-duration for the shorter return period. These curves should be prepared using the appropriate ESSA-Weather Bureau Technical papers or charts (see Chapter 2, paragraphs 3c or d).

(4) Plotted centerline profiles of all 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) Information on existing and future aircraft use for selection of appropriate strength for grates, covers, and frames for inlets and manholes.

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 30.

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.

18. 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 30), 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 safety areas. 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 necesary to warp the grade to provide a smooth transition at the intersection of pavements. As noted on the typical cross section of Figure 31, the intermediate areas of the runway safety area, each side of the runway pavement will be on a 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 ridge shown in Figure 8 will protect the area around the inlet, prevent by-passing, and facilitate the entry of the water into the structure. If the ridge area is within the runway safety area, the grades and grade changes will need to conform to the limitations established for runway safety areas in other advisory circulars. 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 base or subbase and 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 28. 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, differentation 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 32).

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

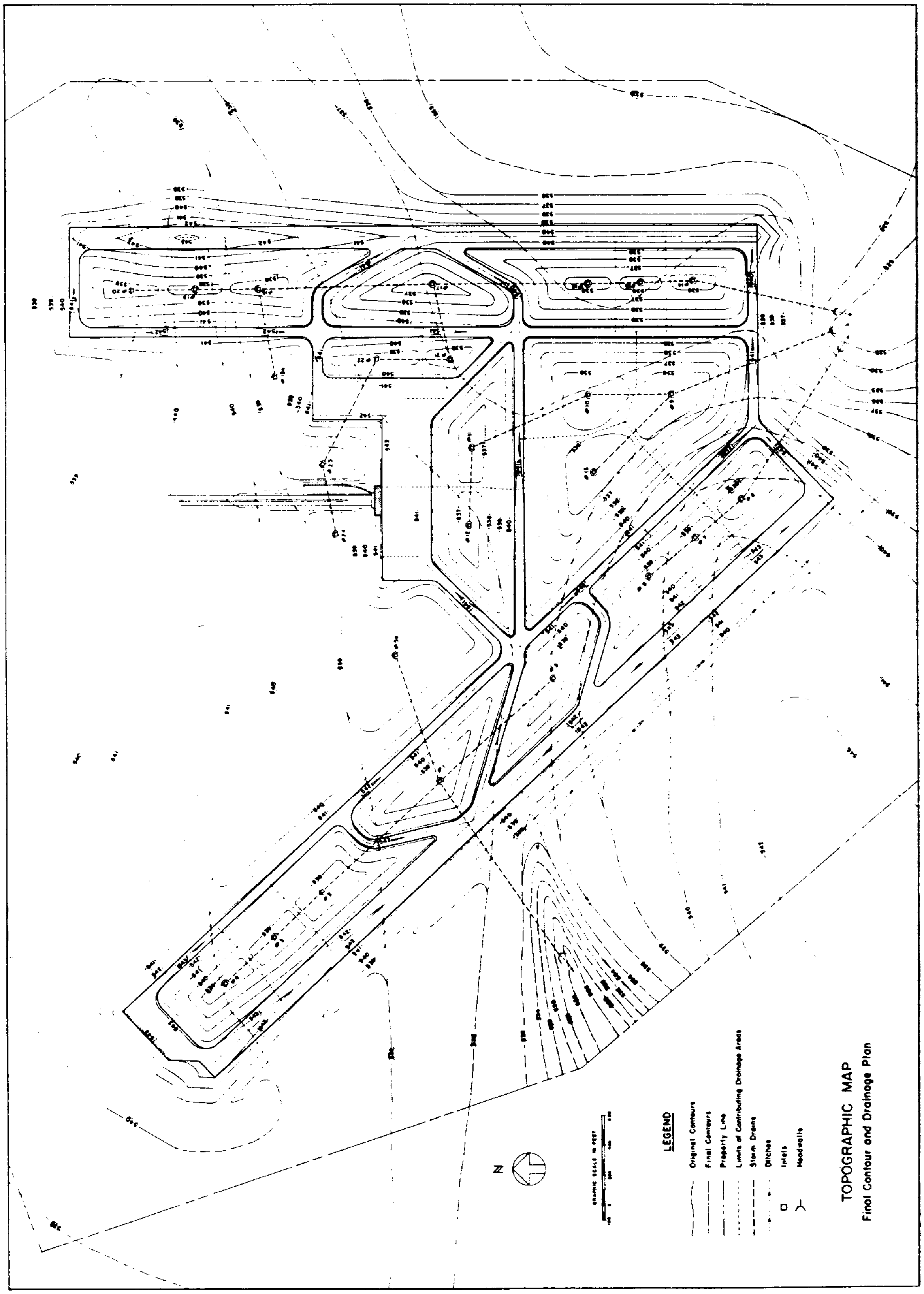


FIGURE 30. Topographic map.

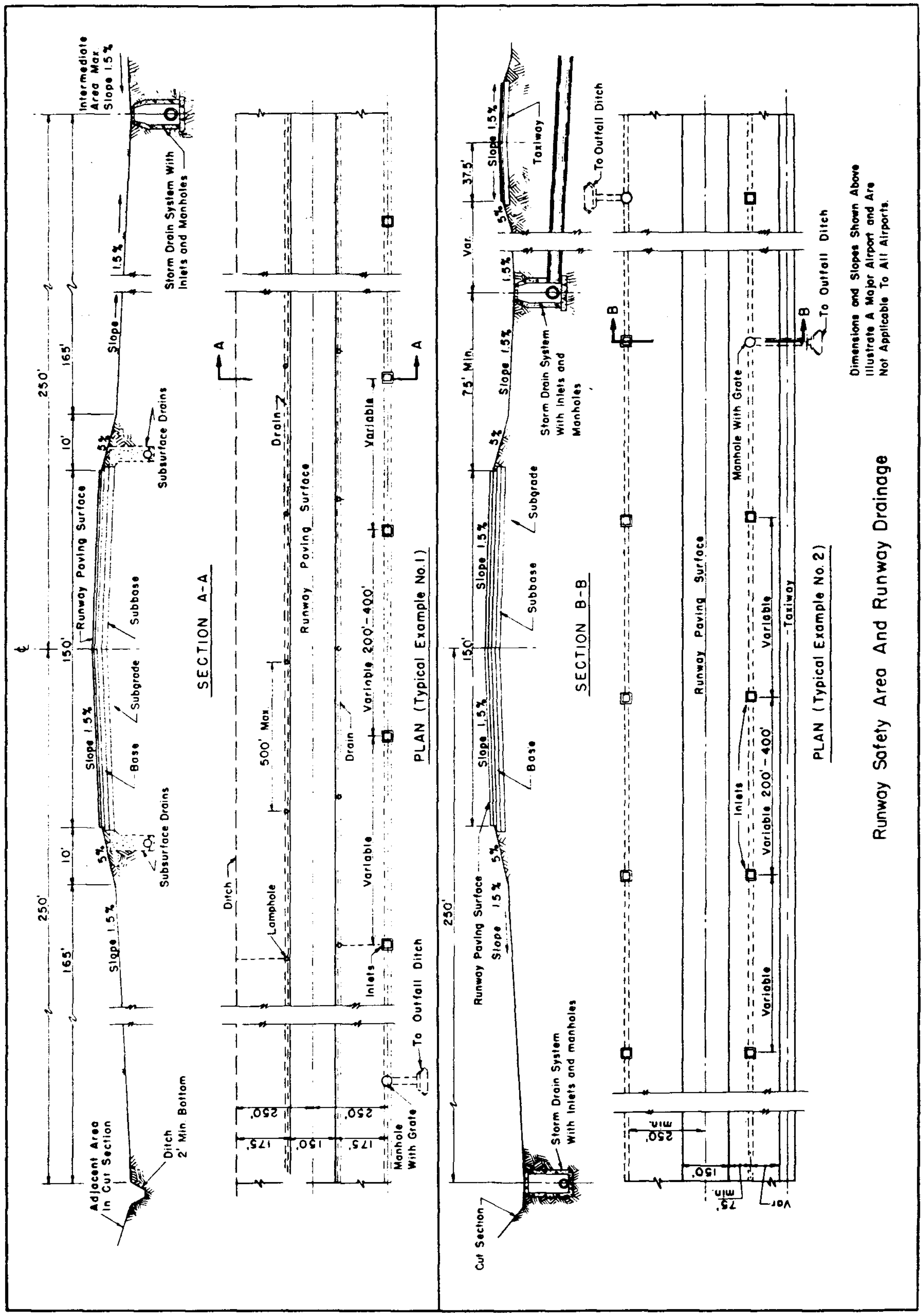


FIGURE 31. Runway safety area and runway drainage.

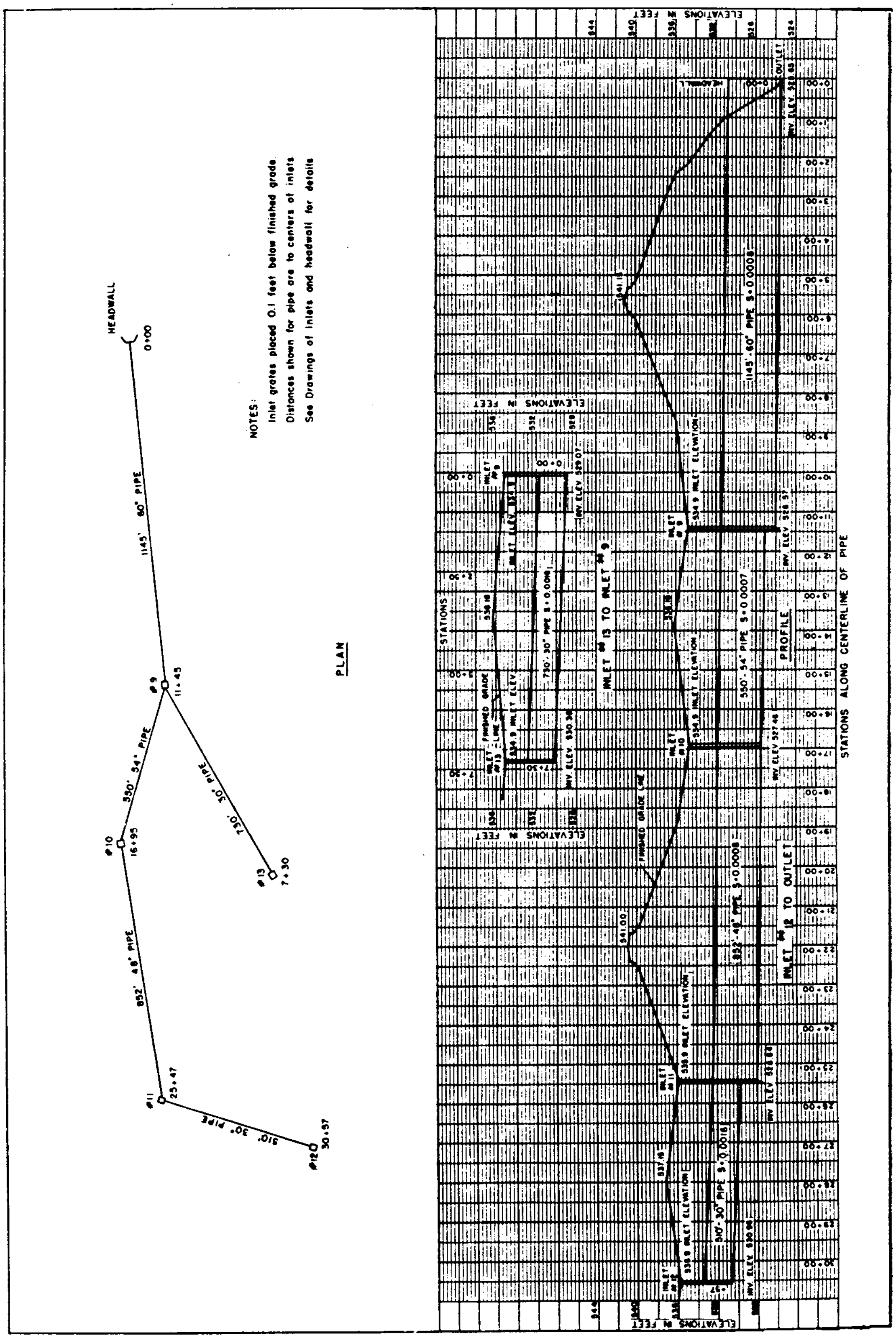


FIGURE 32. Plan and profile of drainage pipe.

g. Ditches form an integral part of the drainage system. The size of the ditches and their functions are quite variable. Some ditches serve 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, stabilized, or lined to control erosion.

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 estabish the lengths of pipe segments between structures. Scaled dimensions are of sufficient accuracy at this stage.

(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 7. If the distance exceeds the limits of the curves, use the formula in Figure 7. 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 pipe size which will carry the runoff. Charts as shown in Figures 9 through 12 may be used.

(i) As the design progresses along the line, the runoff naturally accumulates. Each succeeding pipe run carries the water from the upper reaches of the system in addition to the water introduced through its immediate inlet structure. This accumulation, however, is not necessarily a straight arithmetic summation of flows from preceding inlets. Flow from influent lines may have to be adjusted to represent the amount of water which they are contributing at the time of concentration for the point being investigated.

19. SURFACE DRAINAGE.

a. A portion of the actual design of the system can now be considered in accordance with criteria and data given previously. For example, the area between the apron and taxiways of the airport layout has been selected for detail analysis in making the necessary calculations and determinations (see Figure 33).

b. The rainfall data for the location under study has been obtained from graphs found in the U.S. Weather Bureau Technical Paper No. 40. These data have been plotted and curves drawn (Figure 6) to indicate the intensity of rainfall. The curve of the intensity-duration for a 5-year frequency will be used in the computations. From this curve, the intensity for the corresponding time of concentration for each inlet can be readily determined and used in the system design.

c. After the drainage layout has been decided and sketched on drainage working drawings, the extent of the subarea contributing to each intake structure is measured and tabulated. The recording of the sizes of the subareas is shown in Table IV. Inspection of the areas will show that surface water will flow partly over pavements and partly over turfed areas. A runoff factor of 0.90 has been assumed for the paved areas and 0.30 for the turfed areas. A weighted value of the factor "C" or runoff coefficient was calculated as explained in Chapter 2 and is shown in Table IV. In working up the data shown in Table V, a bell-and-spigot type of pipe was used and a value of $n = 0.015$ was assumed.

d. For convenience in the computations and recording the results, a form such as that of Table V is suitable. Explanation of the various columns of this form is as follows:

(1) Column I identifies the inlet being investigated. All structures should be numbered, preferably starting with the first structure from the outfall and progressing along the line to the uppermost end.

(2) Columm 2 identifies the particular segment of the drainage system being designed.

(3) Column 3 shows the length of that segment of the line.

(4) Column 4 gives the "inlet time" or time required for water to flow overland from the most time-remote point of the tributary subarea to the inlet being considered.

(5) Column 5 gives the "flow time" through the particular pipe segment. This is obtained by dividing the pipe length by the velocity of the drain. See column 12 for velocity.

(6) Column 6 shows the time of concentration. For inlets 12 and 13 in the example, time of concentration equals the "inlet time." Maximum flow does not occur at inlet 11 until all areas tributary to it are contributing to that inlet. All areas are contributing to inlet 11 in 55.4 minutes (see note in Table V).

(7) Column 7 shows the coefficient of runoff for the subarea contributing to the inlet. A method of determining the runoff factor is illustrated in Table IV.

(8) Column 8 gives the rainfall intensity based on the time of concentration and the design storm frequency (from Figure 6).

(9) Column 9 gives the acreage of the subarea immediately tributary to the inlet being investigated. (See Table IV.)

(10) Column 10 shows the amount of runoff from each tributary area as determined by the Rational Method formula $Q = CIA$.

(11) Column 11 gives the accumulated runoff which must be accommodated. In the example problem the maximum accumulated runoff to be discharged from inlet 11 consists of the runoff from the subarea tributary to inlet 12, plus the amount of runoff from the subarea tributary to inlet 11. The total accumulated runoff at inlet 11 is shown in the table.

(12) Column 12 gives the velocity of flow through the pipe, determined by dividing the pipe capacity by the area of the pipe. To be self-cleaning, drains should be designed to have a flow velocity of not less than 2.5 f.p.s.

(13) Columm 13 gives the size of the pipe required to accommodate the flow.

(14) Column 14 shows 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 capacity, and elevation of discharge basin or channel.

(15) Column 15 shows 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 9 through 12).

(16) Column 16 gives the invert elevation of the structure identified in Column 1.

(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

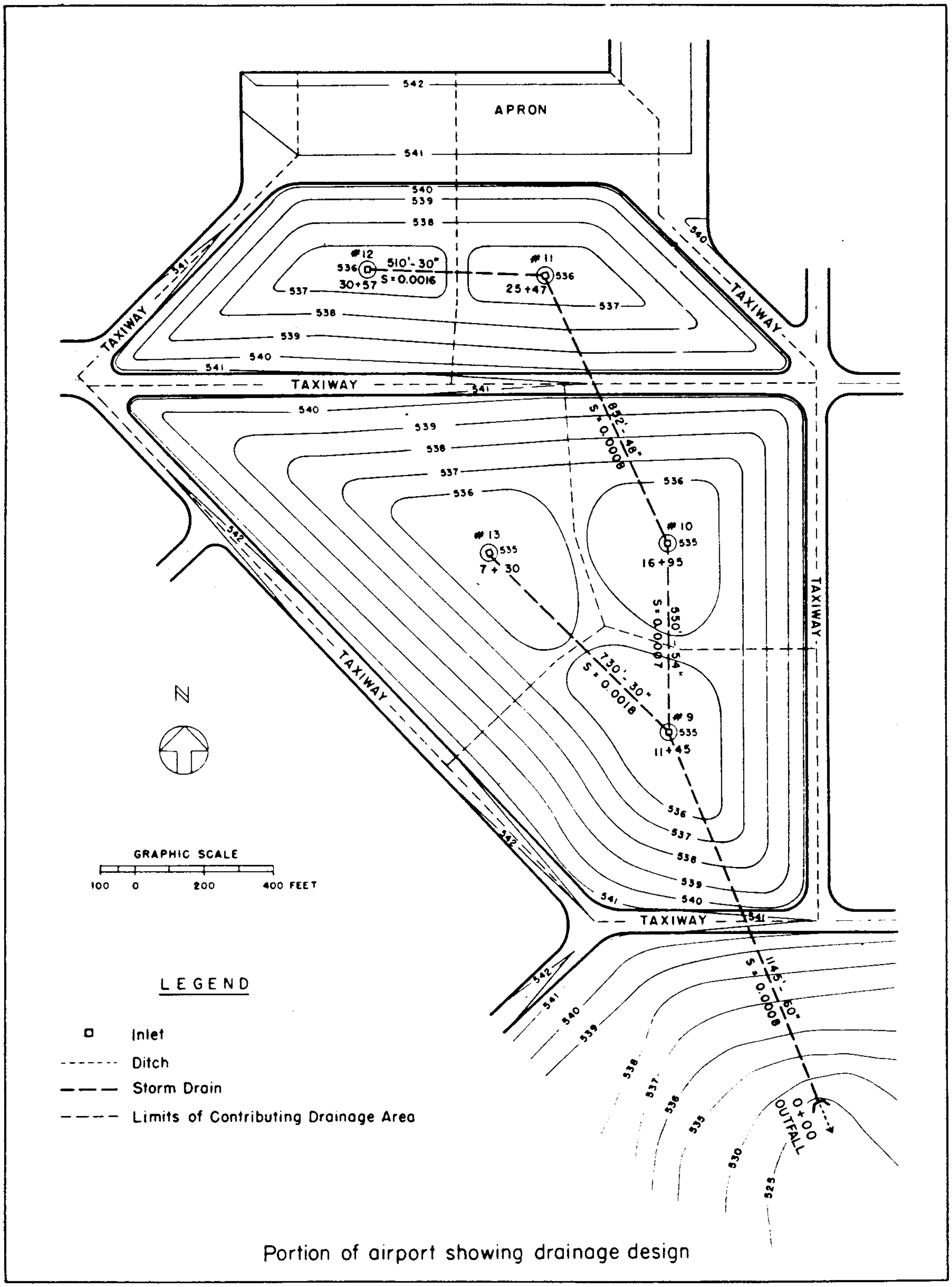


FIGURE 33. Portion of airport showing drainage design.

TABLE IV. Design data for drainage example in Table V

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	48	52
11	5.48	9.24	14.72	29.41	90	750	840	4	49	53
10	1.02	10.95	11.97	41.38	65	565	630	3	36	39
13	1.99	19.51	21.50	21.50	110	1140	1250	4	58	62
9	1.46	14.59	16.05	78.93	85	612	697	4	38	42
Totals	14.73	64.20	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)

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

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

$$C = 0.35$$

Subtotals are shown to illustrate that the area contributing to downstream inlets is a summation of tributary areas above them plus the area contributing to the inlet itself. This prevails where time of concentration for the inlet in question is also a summation - see paragraph 6b (1).

In runoff calculations the accumulation is actually made by addition of the runoff from the line segments (as shown by Table V).

TABLE V. Drainage system design data

DRAINAGE SYSTEM DESIGN DATA

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Inlet	Line Segment	Length of Segment	Inlet Time	Flow Time	Time of Concentration	Runoff Coefficient "C"	Rainfall Intensity "I"	Tributary Area "A"	Runoff "Q"	Accumulated Runoff	Velocity of Drain	Size of Pipe	Slope of Pipe	Capacity of Pipe	Invert Elevation	Remarks
		FT	MIN	MIN	MIN		IN/HR	ACRES	CFS	CFS	FT/SEC	IN	FT/FT	CFS		
12	12-11	510	52	3.4	52	0.49	1.98	14.69	14.25	14.25	2.8	30	.0016	14.25	530.96	(n = 0.015)
11	11-10	852	53	5.0	55.4	0.53	1.90	14.72	14.82	29.07	2.8	48	.0008	35.0	528.64	See note below
10	10-9	550	39	3.3	60.4	0.35	1.78	11.97	7.46	36.53	2.8	54	.0007	45.0	527.46	See note below
13	13-9	730	62	3.9	62	0.35	1.76	21.50	13.24	13.24	3.1	30	.0018	15.0	530.38	
9	9-OUT	1145	42	4.2	65.9	0.35	1.70	16.05	9.55	59.32	3.3	60	.0008	65.0	526.57	
OUT															525.65	

NOTE: Time of concentration for Inlet #11 is 55.4 minutes (52 + 3.4 = 55.4) which is the most time remote point for this inlet. Likewise time of concentration for Inlet #10 is 60.4 minutes (52 + 3.4 + 5.0 = 60.4) 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 desriability 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.

20. 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 depths 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 34 and 35 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 33 except that for simplification, 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 30-inch diameter pipe. These data have been plotted in Figure 35. Also plotted are the discharge capacities for 21-inch, 24-inch, and 33-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 35, it can be seen that the 33-inch pipe will empty the area in 39 minutes after the start for the cumulative runoff from the 5-year frequency storm and will empty the area in 51 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 82,985 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. One objective should be to limit the ponding to less than 243,300 cubic feet, and it will be noted that even the 21-inch pipe would accomplish that. Another objective should be to dispose of the ponded volume in a reasonable time so as not to have ponds in the runway safety area for long periods. Also, a prolonged storage of water may make the area unstable for some time after the storm and may kill the grass. For example, note that the 21-inch pipe would not empty the pond from a 5-year storm for more than 3 hours. The 30-inch pipe would, however, empty the pond in less than an hour. Under these circumstances, the 30-inch pipe would be a more acceptable selection, however, the 21-inch pipe might result in the hazards mentioned above.

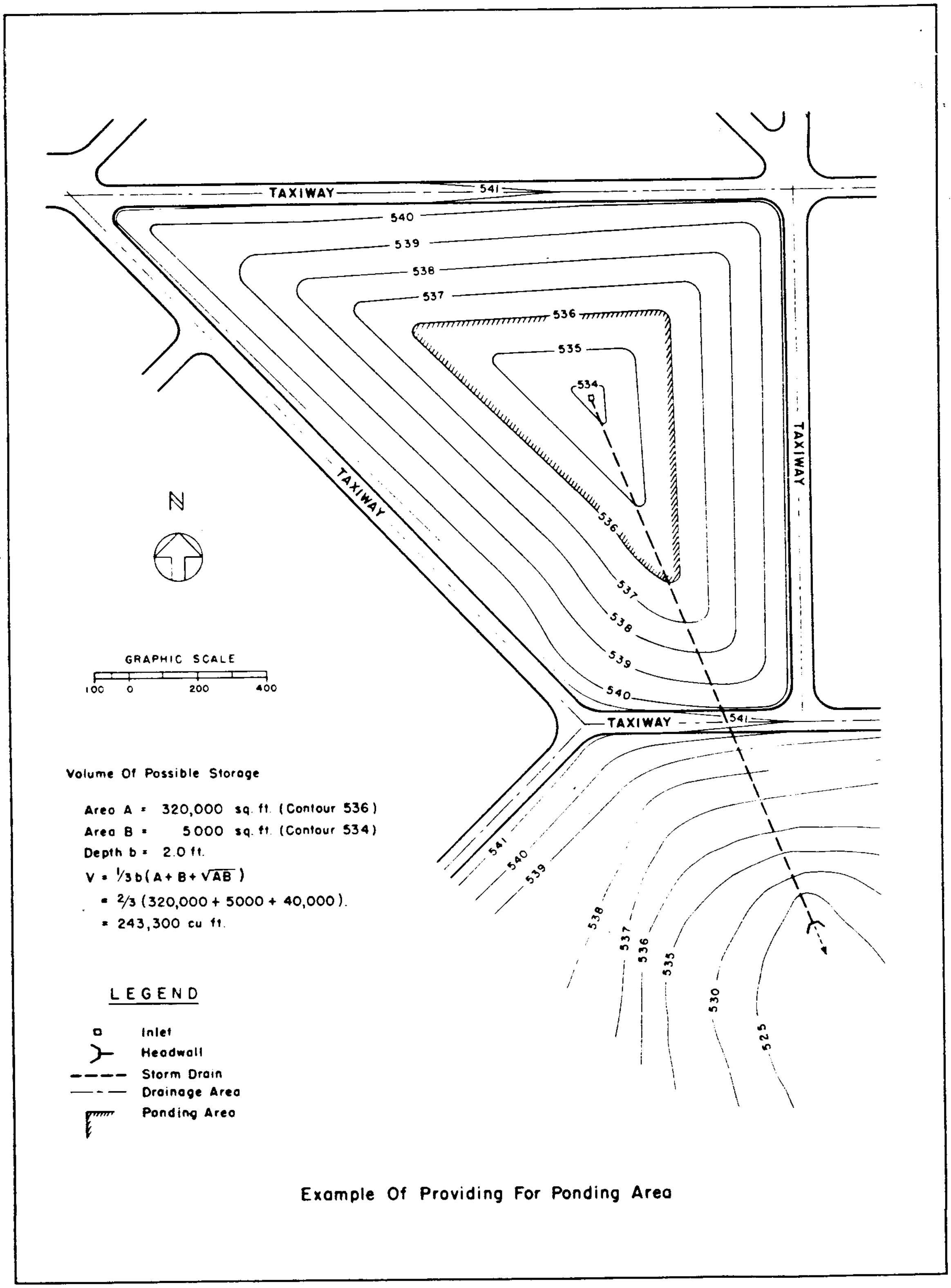


FIGURE 34. Example of providing for ponding area.

TABLE VI. Computations for ponding example in Figures 34 and 35

COMPUTATIONS FOR PONDING EXAMPLE IN FIGURES 34 AND 35

Hourly Intensities for Various Time Intervals from Figure 6

Time	5 yr. Frequency	10 yr. Frequency
5 min.	6.12	6.96
10 min.	4.68	5.34
15 min.	3.96	4.48
20 min.	3.40	3.90
30 min.	2.74	3.12
60 min.	1.76	1.97
90 min.	1.28	1.45
120 min.	1.05	1.23

Q = CIA
A = 4.47 Acres, Pavement
= 45.05 Acres, Turf
= 49.52 Acres, Total
C = 0.90 For Pavement
= 0.30 For Turf
I = 1.50 In. (From Fig 6 for 75.2 min.)
Q = 0.354 x 1.60 x 49.52 = 26.29 c.f.s.
n = 0.015 S = 0.7% 30" pipe will carry 30 c.f.s.

Distance most remote point — 1600'
120' across pavement, 1480' across turf
Concentration Time: 4.5 + 70.7 = 75.2 minutes

$$\text{Average } C = \frac{4.47 \times 0.90}{49.52} + \frac{45.05 \times 0.30}{49.52} = 0.354$$

CA = 49.52 x 0.354 = 17.53
Runoff rate when all areas contributing
1 hr. = 3600 x 30 = 108,000 c.f.

Cumulative Runoff in cu. ft.
I = 6.12 (From above)
Q = CIA CA = 17.53
Q = 17.53 x 6.12 = 107.28 c.f.s.

For 5 min. for 5 yr. storm
5 min. = 300 seconds
107.28 x 300 = 32185 cu. ft.*

Thus:

Minutes	Cu. Ft. Supplied By 5 Yr Storm	Cu. Ft. Supplied By 10 Yr Storm
5	17.53 x 6.12 x 300 = 32185*	17.53 x 6.96 x 300 = 36603
10	17.53 x 4.68 x 600 = 49224	17.53 x 5.34 x 600 = 56166
15	17.53 x 3.96 x 900 = 62477	17.53 x 4.48 x 900 = 70681
20	17.53 x 3.40 x 1200 = 71522	17.53 x 3.90 x 1200 = 82040
30	17.53 x 2.74 x 1800 = 86458	17. 3 x 3.12 x 1800 = 98448
60	17.53 x 1.76 x 3600 = 111070	17.53 x 1.97 x 3600 = 124323
90	17.53 x 1.28 x 5400 = 121167	17.53 x 1.45 x 5400 = 137260
120	17.53 x 1.05 x 7200 = 132527	17.53 x 1.23 x 7200 = 155246

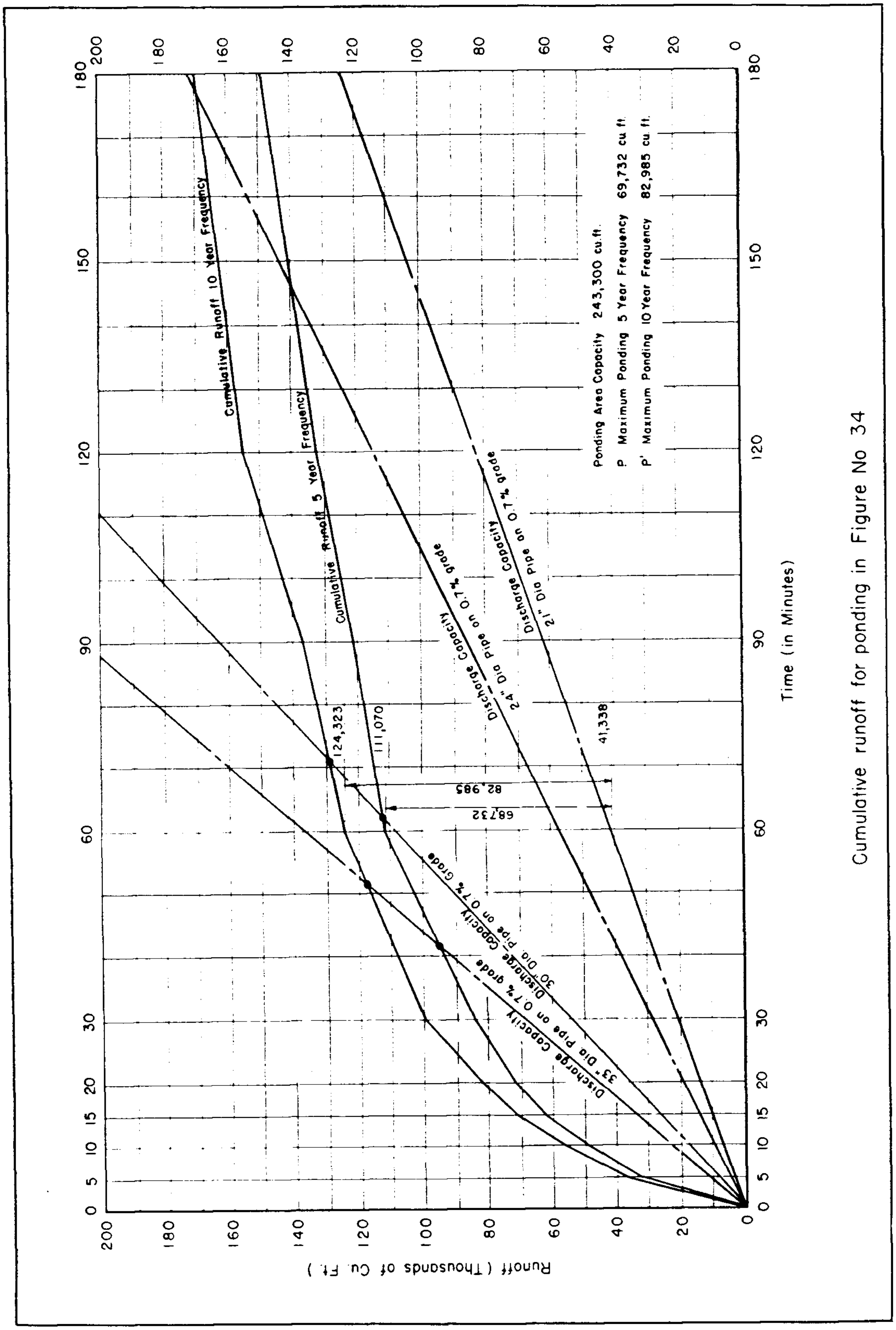


FIGURE 35. Cumulative runoff for ponding.

21. 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 shoud 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 details of a comprehensive soil survey are covered in Chapter 2 of AC 150/5320-6A. The water 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 36 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, 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 37. 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, 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 wil 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.

(4) Although the above general soil classifications are helpful in deciding where subsurface drainage will be practical, the perviousness of a given soil, base, or subbase course is measured by the coefficient of permeability. There are several methods of determining the coefficient—both in the laboratory and in the field. The coefficient of permeability is expressed as centimeters per sec. (1 cm./sec. = 1.97 ft./min.) representing rate of flow. The range of coefficients is very large so they are usually expressed as values with exponents ranging from the most permeable at 10^2 to very impermeable at 10^{-9}. The value 10^{-4} is a useful reference point as a soil with such a coefficient is just able to drain a very heavy rainfall. The coefficient of permeability of untreated base and subbase courses depends principally upon the percentage by weight of the fraction passing the 200-mesh sieve. For example, on that basis material meeting FAA construction Specifications P-154, P-208, or P-209 would have coefficients ranging from 10^{-1} to 10^{-4}.

A Corps of Engineers study shows, however, that the drainage characteristics of base course materials may also depend on the density of the material. Increases in density (compaction) cause large decreases in permeability and moderate decreases in effective porosity. Moreover, the drainability of a highly compacted material can approach zero when it contains as little as 5 percent fines (passing the 200-mesh sieve).

The investigation of need for subsurface drainage to protect the pavement subgrade should therefore include a determination of permeability of subgrade soils and pavement courses. Similarly, the practicality of intercepting drains could be indicated by the coefficient of permeability of the soil in the area selected for installation of the drain pipe.

Pavement courses that have been adequately stabilized with cement or bitumen are impermeable, therefore, a pavement edge drain system would be unnecessary. A high water table or other circumstances resulting in wet subgrade soils may, in these cases, best be handled by interceptor drains.

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 36 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 flow from a subsurface system is considerably less than for other types, and the grades are usually flatter. The grades should not be less than 0.15 foot in 100 feet. The type of surface, the soil, the infiltration, the spacing and depth of the drains, the amount of precipitation of seepage, and other factors all affect the flow and, therefore, the size of the pipe needed.

(1) The rate of infiltration for subdrainage that is commonly used is 0.25 to 0.50 of an inch in 24 hours. A rate 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 infiltration is known the proper size of pipe may be determined from Figures 9 through 12.

h. Generally, a single line of subsurface drains along the pavement edges is sufficient for the width of most runway and taxiway bases. It may be necessary on bases wider than 75 feet from crown to edge—such as on aprons—to install intermediate lines of drains. Item 7 of the bibliography is a source of design procedure and criteria for determining the spacing of such intermediate drains.

i. The types of pipe used for subdrains are: plain or perforated vitrified clay or concrete pipe, perforated corrugated aluminum alloy pipe, perforated corrugated steel pipe, cradle invert vitrified clay pipe, perforated asbestos-cement pipe, perforated bituminous-fiber pipe, and porous concrete pipe.

j. 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.

k. 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 or the pavement with the backfill material in the subdrain system. The subsurface drains should be installed in accordance with "C" in Figure 37. As shown on the drawing, these drains need not be large; and, under normal conditions, a pipe 6 or 8 inches in diameter will suffice.

It is necessary to have access to subdrains for observation and flushing. Inspection/flushing holes are usually spaced no more than 500′ apart. They are constructed of the same type and size pipe as the subdrain with a grate or cover at the surface.

l. In some localities, low temperatures and snowfalls result in deep frost penetrations and deep accumulations of snow on the pavement shoulder area and adjacent thereto. As a consequence, the thaw period is prolonged and may result in saturation and thus, instability of the subgrade.

Although installation of subsurface drains at the pavement edges is the preferred solution, it has been found that, in some areas, a widened base or subbase works as well and is reasonable in cost (see paragraph 13b(3)).

m. When pervious bases and subbases are used with impervious subgrades, the low area in the longitudinal profile of the pavement can be a troublesome water collection basin. Normally, subdrainage pipes should be installed at the pavement edges to provide an outlet for that water. In some cases, however, french drains (trench sections filled with pervious material) leading from the base and/or subbase outward into the shoulder area will provide some relief.

n. The construction specifications should require backfilling the subsurface trenches with well compacted granular material to act as a filter. 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.

o. 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 and the fine material is well graded. If the fine material (natural foundation soil) is uniformly graded, then the 15-percent size of the filter (backfill) material should be less than 4 times as large as the 85-percent size of the fine material.

(2) The ratio of the permeability of the filter material is also important to allow free water to reach the pipe. Appropriate permeability will be assured by conformance with the following equations:

$$\frac{15\%\text{ size filter material}}{15\%\text{ size foundation soil}} = 5.0\text{ or greater and}$$

$$\frac{15\%\text{ size filter material}}{15\%\text{ size foundation soil}} = \text{not more than } 25.0.$$

(3) 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.

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

(5) 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.

(6) 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.

(7) 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.

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

p. Figure 38 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 or 5 times the 0.25 millimeters. 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. Thus these curves illustrate the piping ratio requirements. Similarly, they illustrate the permeability ratio requirements.

(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 38 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 as many different soil gradations may be encountered. Figure 39 illustrates several soil gradation curves and also indicates the theoretical curve (No. 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.

(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 39 indicates that the specification limits of commercial size concrete sand meet this requirement for the well-graded soil No. 4. However, the permeability ratio requirement of 15 percent size versus 15 percent size being greater than 5.0 would require that curve No. 8 be used. Accordingly, the concrete sand should be checked against curve No. 8. 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 39 contemplates the use of the commercial size concrete sand for the backfill material adjacent to the well-graded soil No. 4 to prevent infiltration. Assuming that the openings in the drainpipe 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 (larger size material) by using Figure 39 again. A theoretical gradation curve (No. 7) with a piping ratio of 5 is constructed for the finer backfill material by using 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

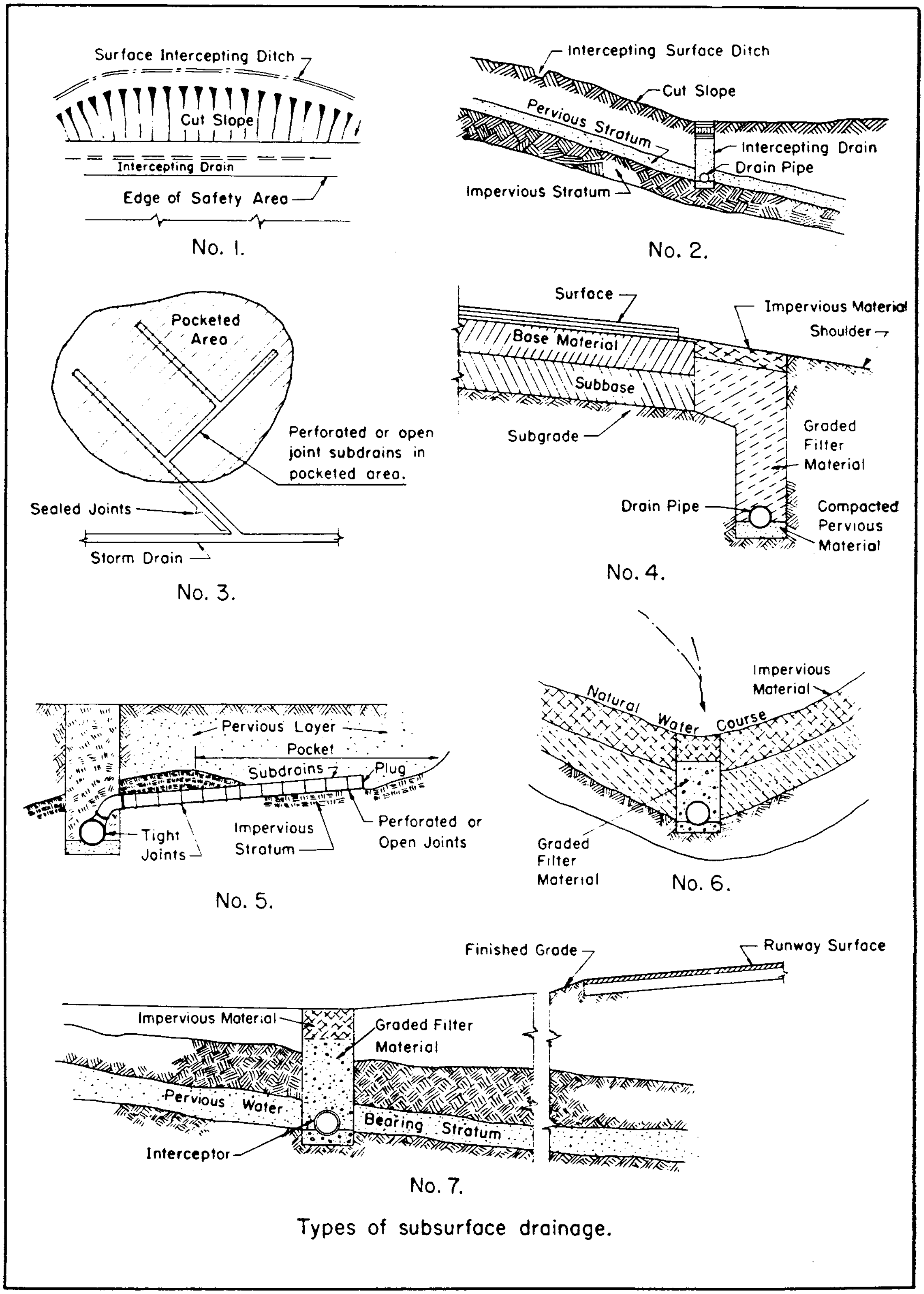


FIGURE 36. Types of subsurface drainage.

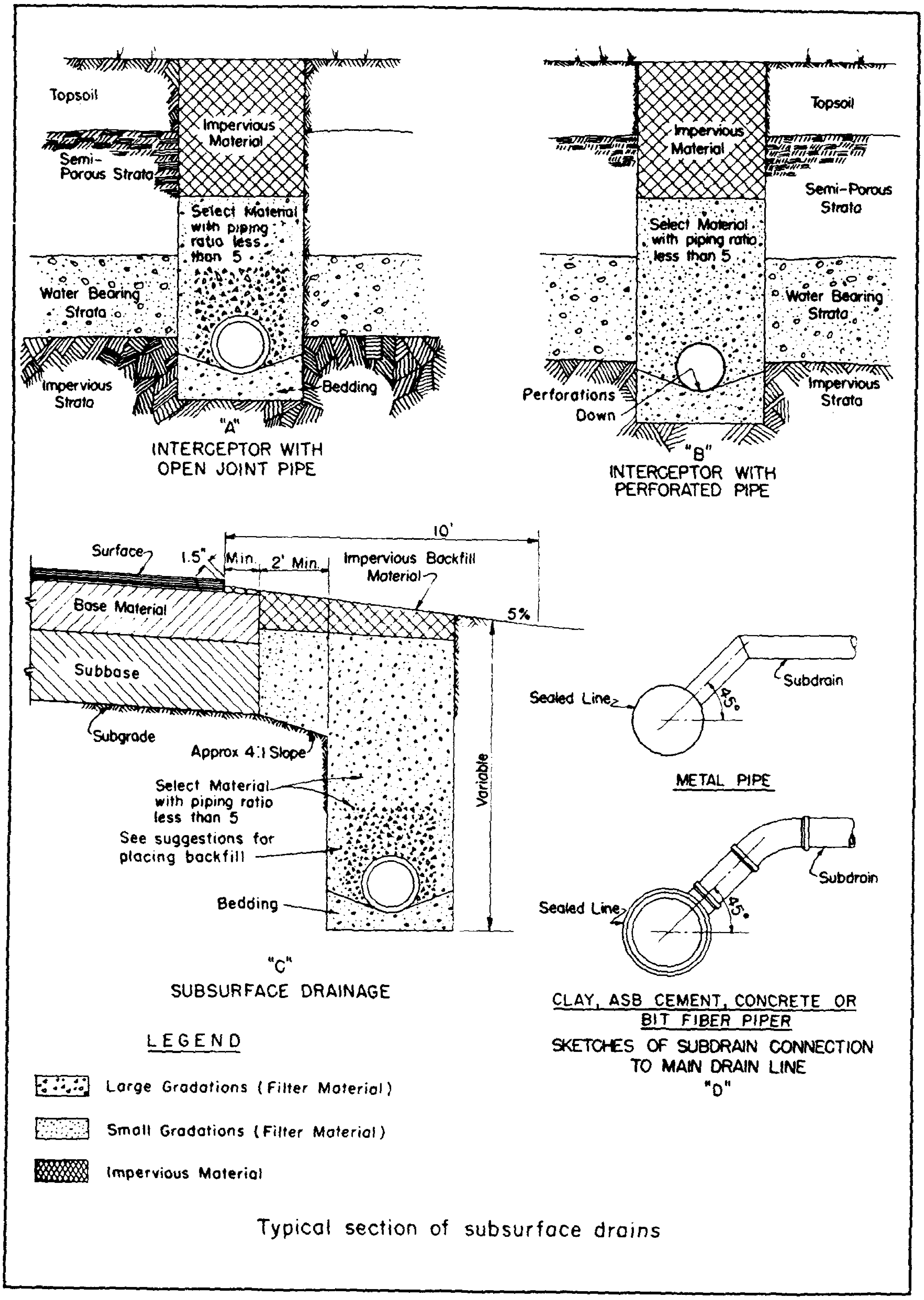
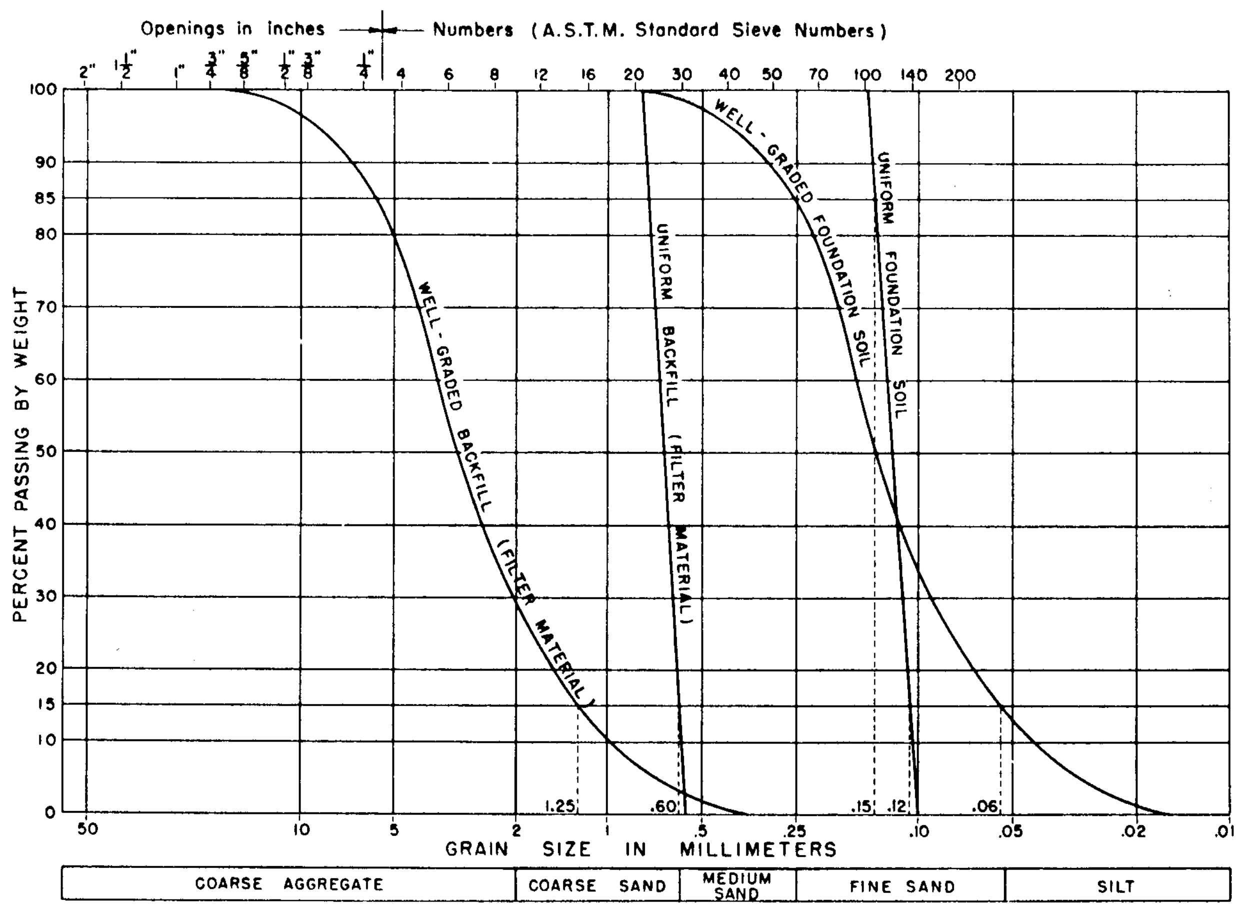


FIGURE 37. Typical section of subsurface drains.



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 38. Gradation of backfill for subsurface drains.

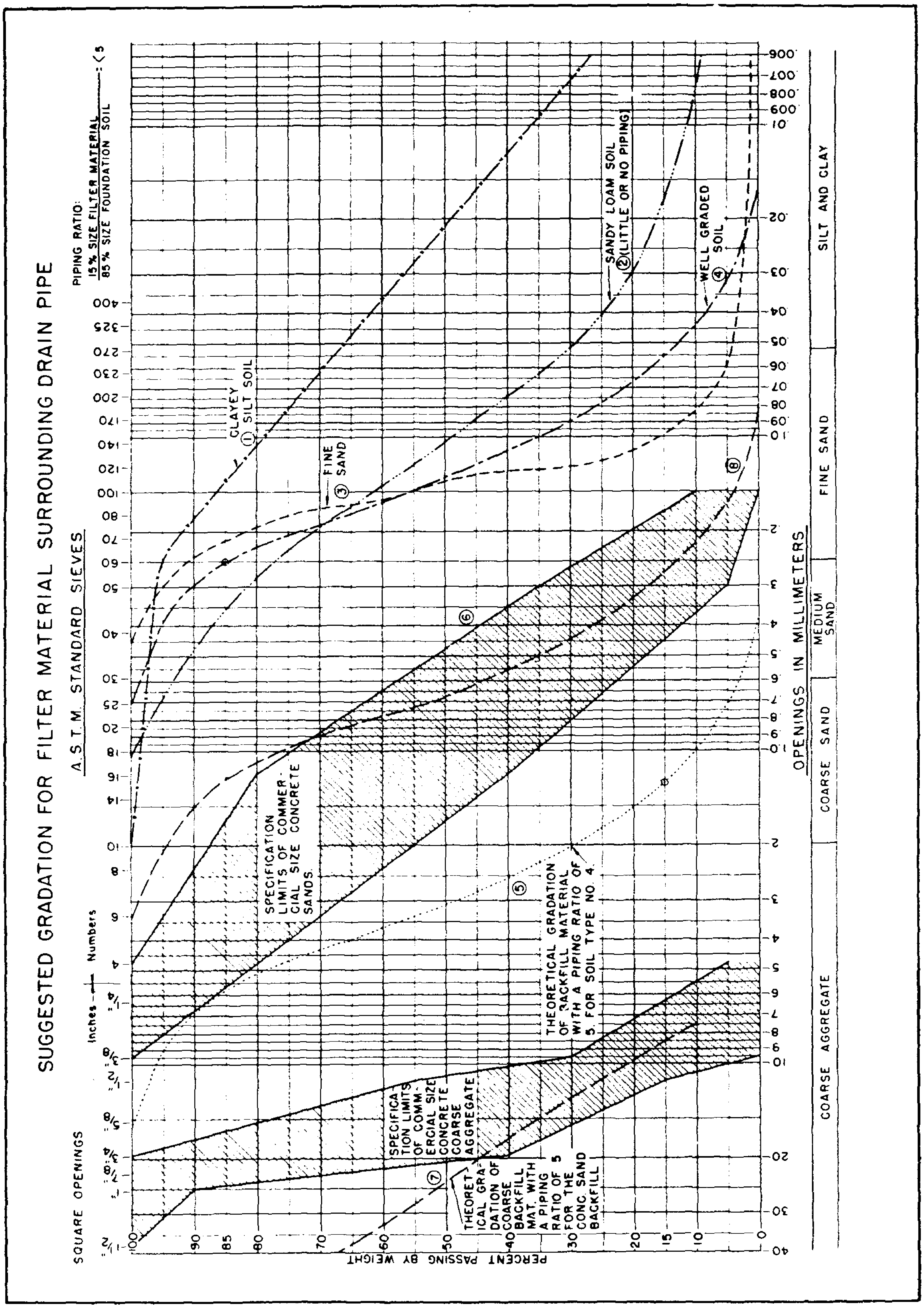
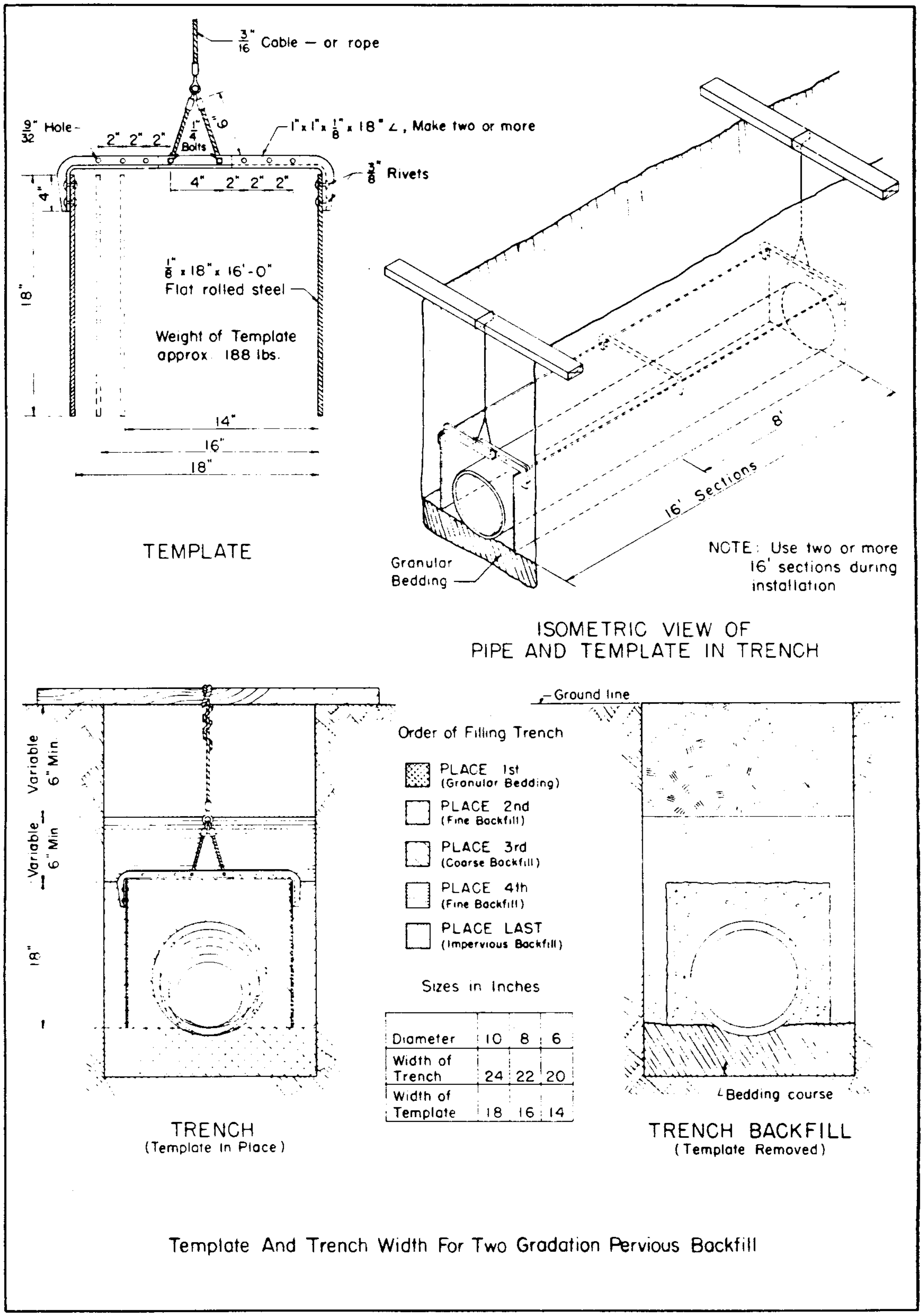


FIGURE 39. Gradation for filter material.



Template And Trench Width For Two Gradation Pervious Backfill

FIGURE 40. Template and trench width for pervious backfill.

size will indicate the material most difficult to control. This new curve No. 7 indicates that the courser side of the gradation band of 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.

q. During the past few years, industry has developed woven plastic filter cloths which have been found to be satisfactory for protection against beach erosion, for protection against steep slope erosion and as a filter in subsurface drain installations.

In the latter connection, note that paragraph o above refers to the possibility of even well-graded granular filter materials moving into pipe openings or perforations. It is recognized too, that gradations of granular material, meeting the piping ratio and other requirements of paragraph n above, may not be economically available. In these cases, a single wrap of woven filter cloth around the pipe may be used in lieu of the coarser backfill illustrated in Figure 40. Filter cloths have openings with a size generally like the No. 40 sieve. The cloth may be wrapped around open joints of unperforated pipe or around the entire length of perforated pipe. Prefabricated filter cloth sleeves may also be used to encase the pipe. When the gradation of granular filter material is such that it satisfies requirements pertaining to material adjacent to joint openings or pipe perforations, but is too coarse to satisfy the filter criteria pertaining to the protected soil, a single layer of filter cloth may be used adjacent to the protected soil in lieu of a second filter material. This use, however, is restricted to situations where the protected soil is sand.

22. 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 41, 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 150/5370-1A, 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.

23. POLLUTION CONTROL.

Construction of drainage systems and grading as a contributory part of good drainage systems are to be accomplished in a way to control pollution. Sodding or some other form of stabilization of graded slopes and ditches should be done to minimize erosion and prevent pollution of streams and rivers.

Although this advisory circular is aimed at storm water drainage and subsurface drainage and not at sanitary sewer systems, it should be recognized that civil airports often support populations which are sufficiently large to contribute to the pollution of water resources if raw sewage is discharged from the airport structures such as the terminal building. Installation of sewage treatment plants, or diversion to such plants, should be required and should conform with local, county, or State sanitary codes. In either case, the sanitary sewer system should be separate from the storm sewer system.

24. MAINTENANCE OF THE SYSTEM.

a. Maintenance is essential to preserve and prolong the service and utility of all drainage facilities. All structures and visibe 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

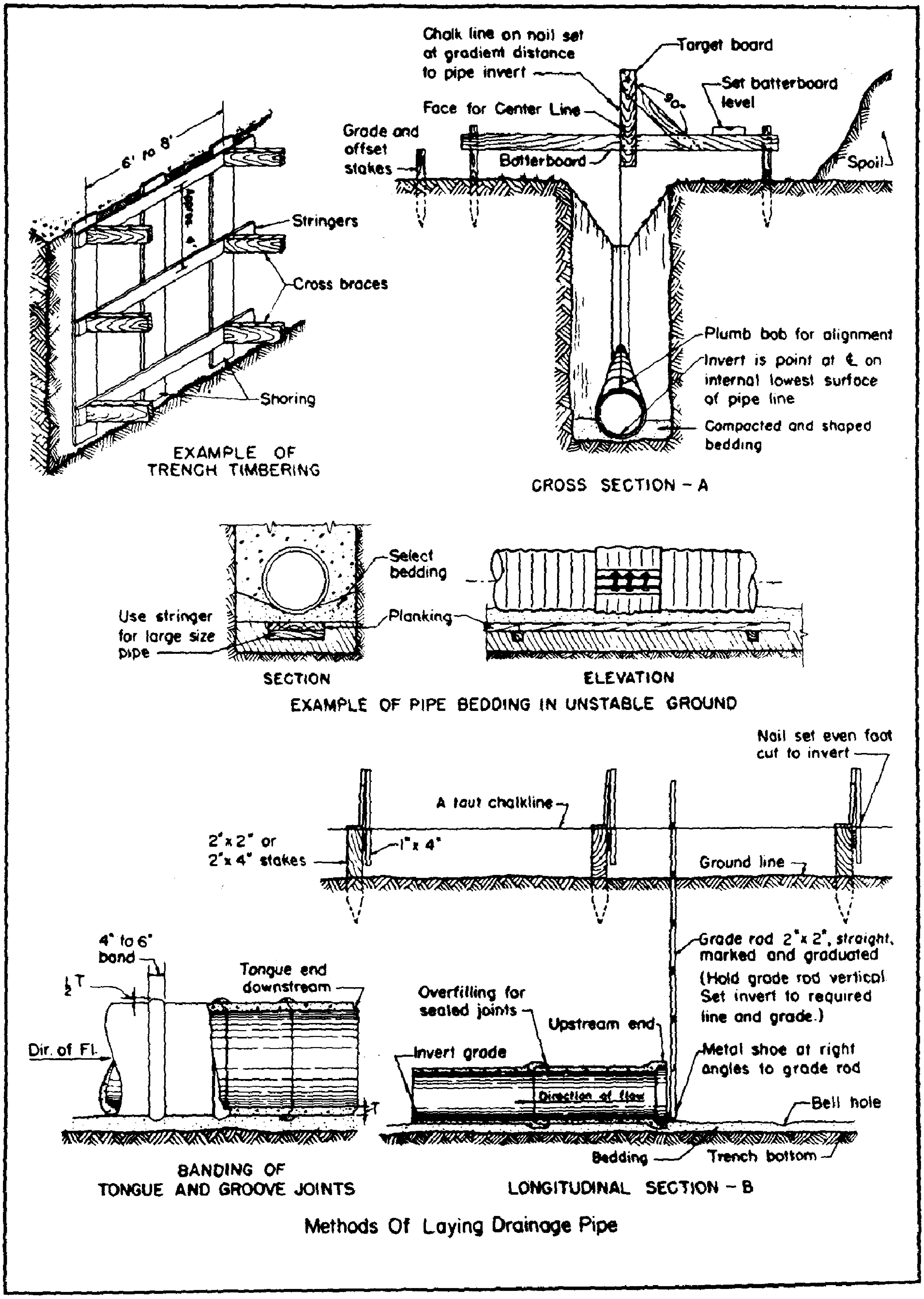


FIGURE 41. Methods of laying drainage pipe.

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. Also, 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.

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