CHAPTER 4

COLLECTION SYSTEM DESIGN

Section I. COMPONENTS

4-1. General

a. Before sewage can be treated properly it must be collected and transported to a central location. If the installation is built as given in TM 5-302, then the complete sewer system may also be built to conform to the sewage design from TM 5-302. Those installations which have water-borne sewage have the sewer layout given. Thus the only design work necessary is to determine the invert elevations and in some cases the slope of the pipe.

b. If the installation is not laid out as shown in TM 5-302, or if an installation is not given completely, the engineer officer must design the sewer system. An example of a collection system and its nomenclature is given in figure 4-1.

4-2. Grease Trap

A grease trap is required at any facility or installation where grease may be discharged into a sewage system. The presence of grease causes one of the most serious difficulties in sewage treatment. Where sewage is discharged into a stream without treatment grease film on the surface of the water retards reoxygenation. Therefore, as much as possible should be removed to prevent deposits of grease on the walls of the sewer and the formation of film on the surface of the water.

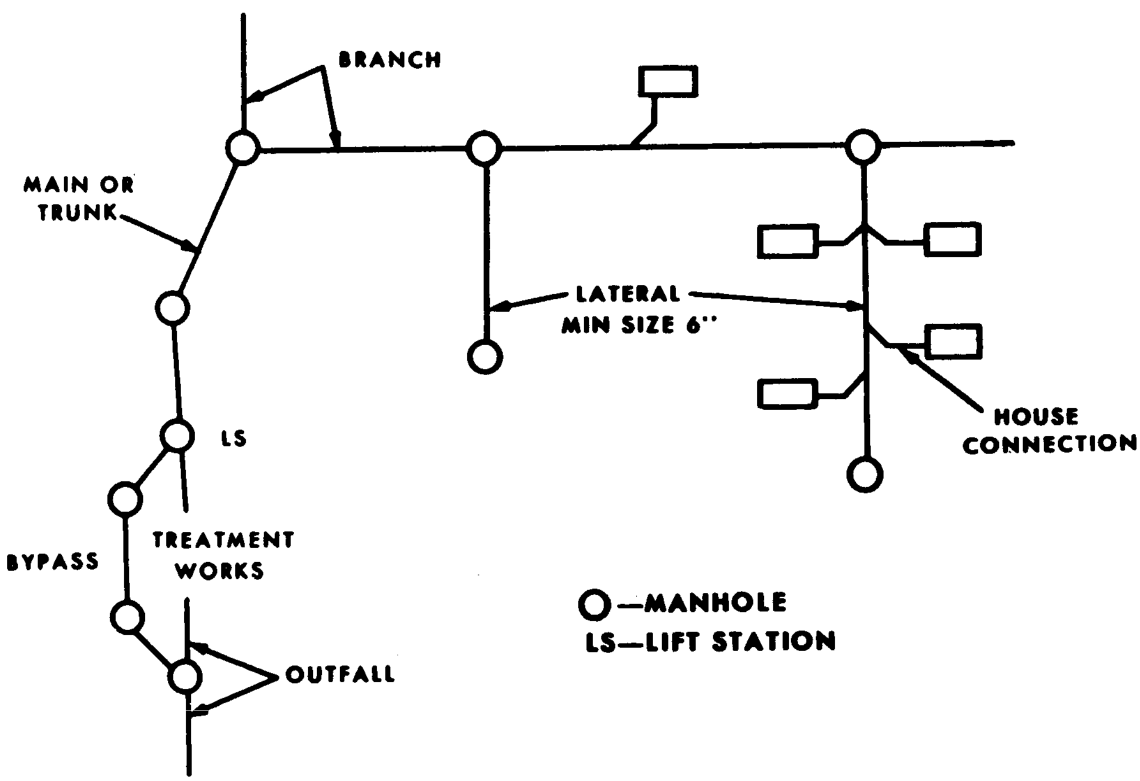

Figure 4-1. Collection system.

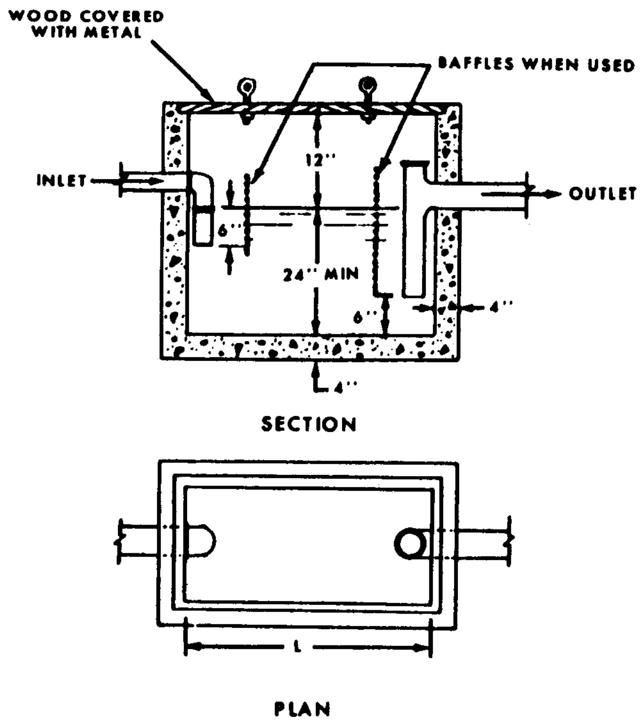

Figure 4-2. Grease trap.

Since grease loses its salvage value after mixing with sanitary sewage, removal at the source is advisable. Grease traps installed as outlined in TM 5-302 achieve this result (fig 4-2).

4-3. House Connections

House connections should be planned to eliminate as many bends as practicable and provide convenience in rodding when required. Generally, connections of house sewers to other sewers should be made directly to the pipe with commercially manufactured fittings rather than through manholes. Manholes may be used, however, if no extra expense would be incurred and should be used if the connection is a greater distance than 150 feet from the nearest cleanout. Where the cleanout inside the building would not be adequate for complete rodding, outside cleanouts, or manholes if cleanouts are impractical, should be provided. For most theater of operations installations, 4-inch diameter sewers on 1% slope will provide adequate capacity. Except where frost or load conditions prevail, one foot of cover will be sufficient for house connections. Figure 4-3 illustrates house connections. Details on this construction are contained in TM 5-302.

4-4. Manholes

a. Standard Manhole. Manholes (fig 4-4) are required at the end of laterals and at each change of direction, slope, or pipe size except for house connections. The distance between manholes should not exceed 400 feet in sewers of less than 18 inches in diameter. For sewers of 18 inch pipe or larger and for outlets from sewage treatment plants, a spacing of 600 feet may be used if the velocity is sufficient to prevent sedimentation. The crown of the outlet pipe from a manhole should be on line with or below the crown of the inlet pipe. Where the invert of the inlet pipe would be more than 18 inches above the manhole floor a drop connection should be provided.

b. Drop Manhole. The only difference between the standard and drop manhole is the difference of elevation of the invert of the manhole. The drop manhole is used to reduce velocities, clear obstacles, and reduce construction effort of ditching along laterals and common sewers (fig 4-5).

4-5. Lift Stations

a. In the theater of operations pumping of sewage should be avoided if possible. However, there are certain conditions under which gravity flow of sewage is impractical or impossible and pumping will be required. Some of the conditions occur when—

(1) The depth of excavation becomes excessive.

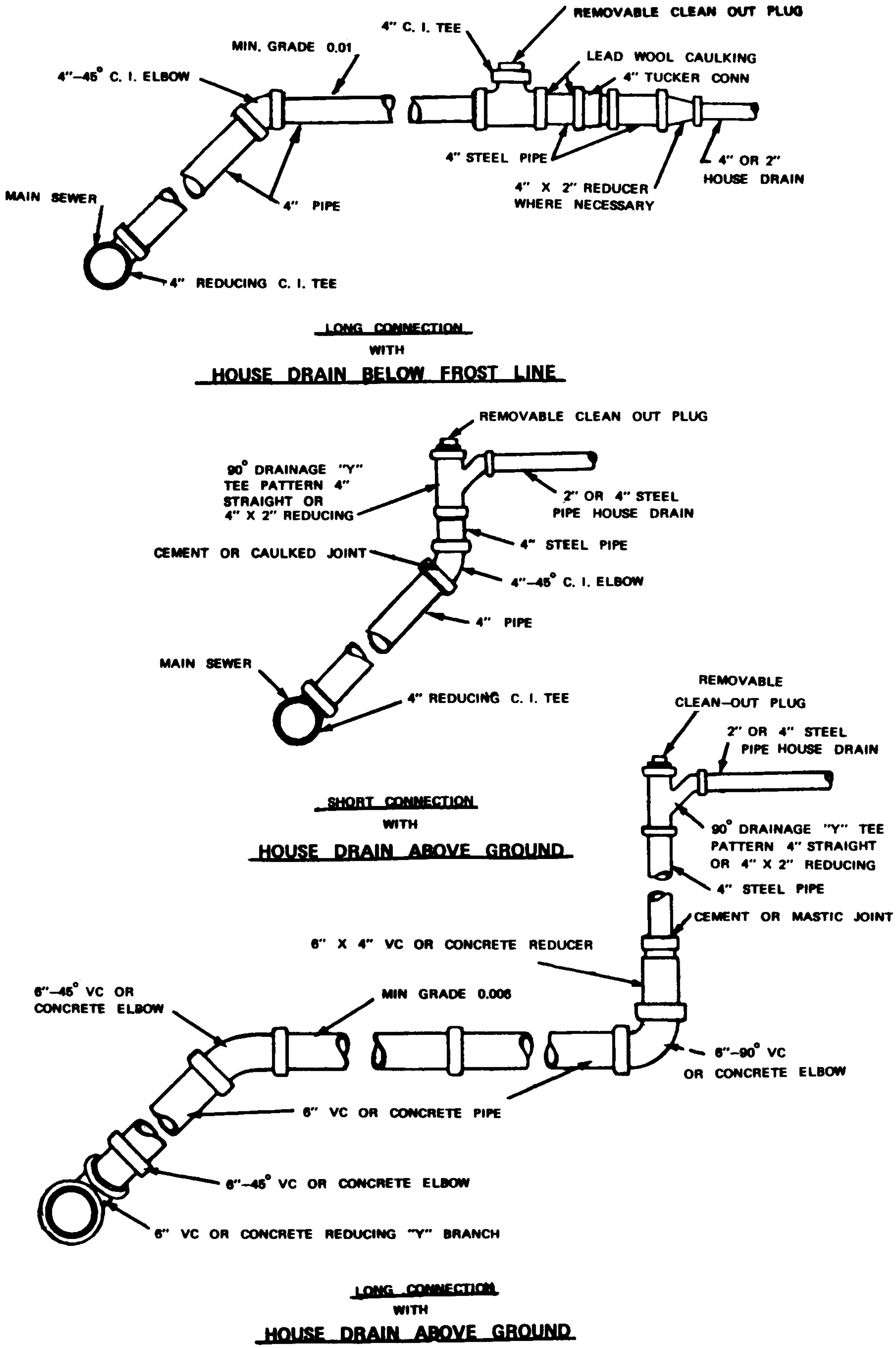

Figure 4–3. Building connections.

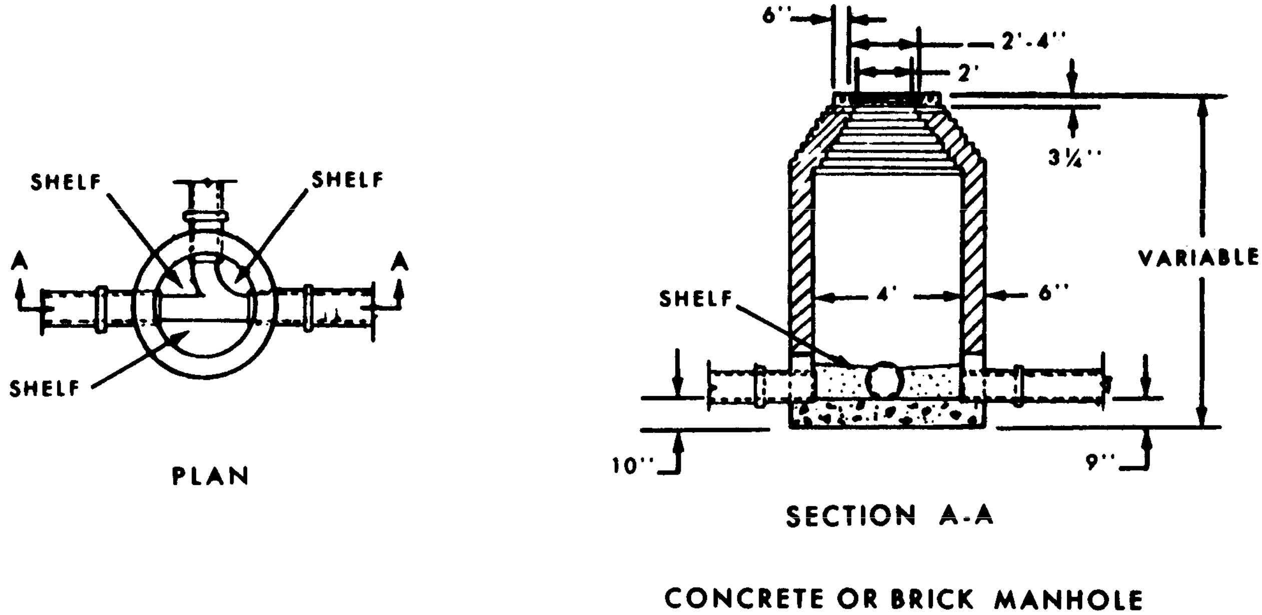

Figure 4-4. Concrete or brick manhole.

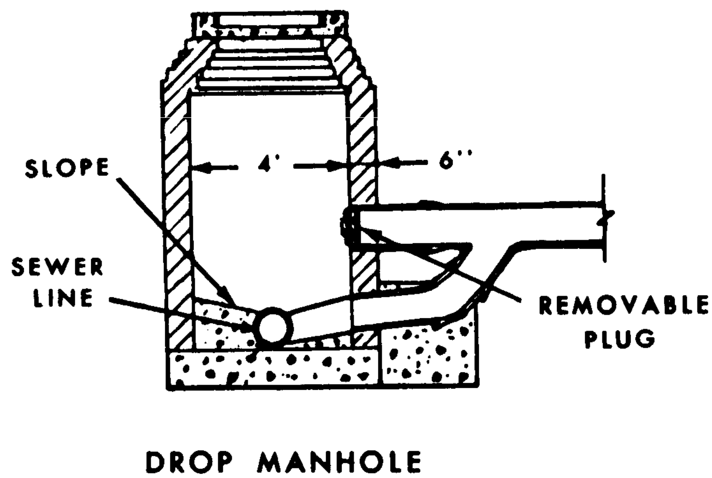

Figure 4-5. Drop manhole.

(2) The sewer outfall is below the level of the receiving stream.

(3) Sewage must be lifted to obtain head for gravity flow through the treatment plant. In all cases the sewage is pumped to a higher elevation and then allowed to continue on by gravity flow.

b. It is necessary to weigh the effort involved in deep excavation versus the cost of the lift station and required maintenance. The situation that would exist if the pumping station failed to operate must also be considered.

c. The lift station is a special design item and must be ordered based on manufacturer's data which are available from the Engineer group. Figure 4-6 shows a typical lift station.

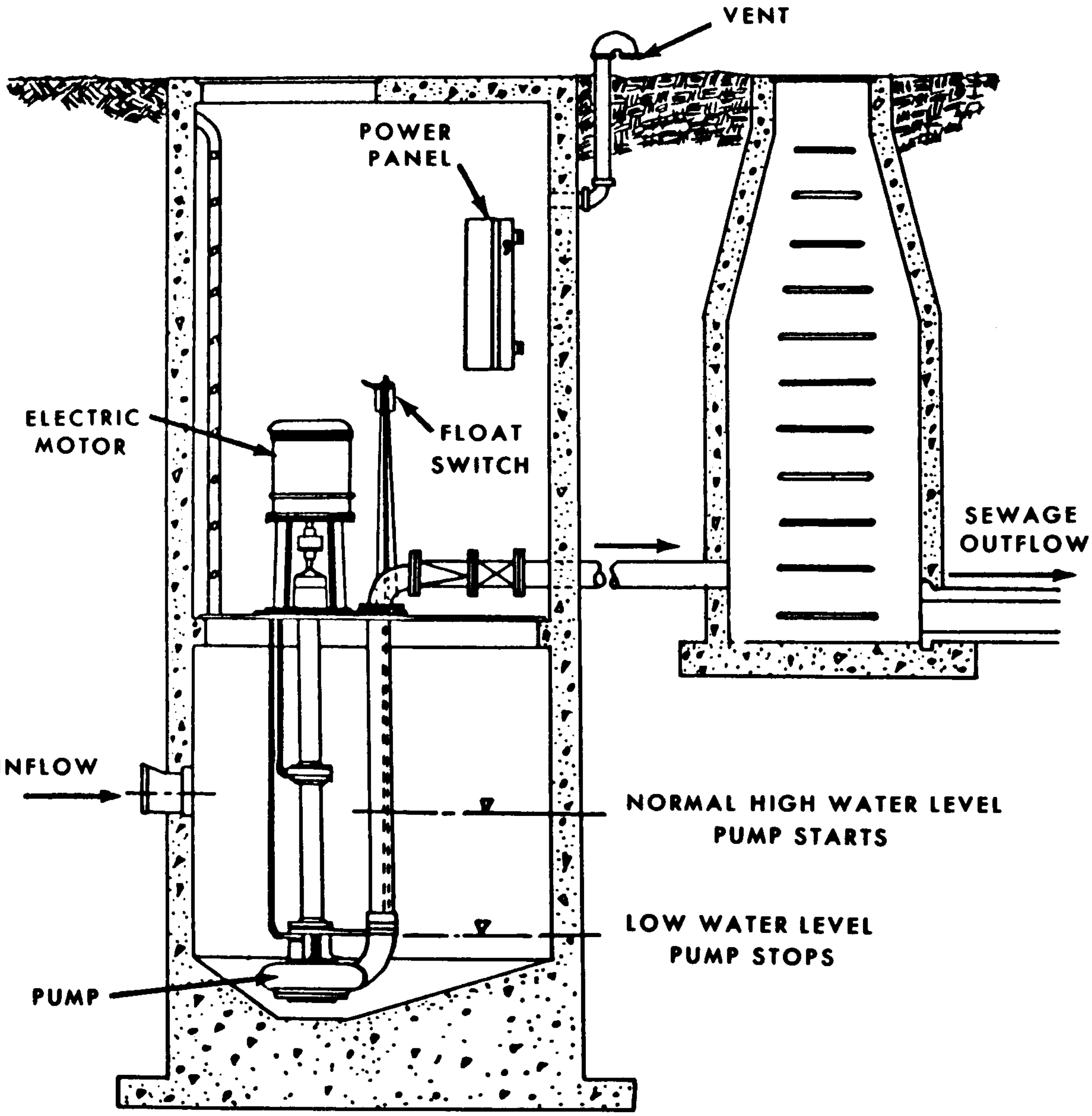

Figure 4–6. Automatic lift station.

Section II. SEWER DESIGN

4-6. General

a. The steps in designing a sewer system are-

(1) Determine sewer layout.
(2) Locate manholes.
(3) Determine flow rates.
(4) Determine slope.
(5) Choose pipe size.
(6) Check actual velocity.
(7) Determine invert elevations.

b. To simplify this process, a worksheet such as the one shown in figure 4–7 should be used. A profile of the sewer system should be drawn as the design proceeds.

4-7. Design Steps

a. Sewer Layout. The development of final sewer plans must await the final site plan, the completion of field surveys and, to some extent, the establishment of floor grades. The development of economical site plans often requires concurrent preliminary planning of the sewer system. The location of lateral and branch sewers will depend not only upon topography, but upon the type and

LATERAL or MAIN		GROUND ELEV.		LENGTH	PEAK FLOW				SLOPE	PIPE SIZE	VELOCITY ANALYSIS					INVERT ELEVATIONS		REMARKS
MAN HOLE																		
FROM	TO	UP	LOW		FLOW INTO	FLOW IN	INFILT	ACTUAL			Q_c	V_c	$\frac{Q_a}{Q_c}$	$\frac{V_a}{V_c}$	V_a	UPPER	LOWER	

Figure 4–7. Sewerage system worksheet.

layout of the housing to be served. Normally, the most practical location would be along one side of the street. In other cases they may be located behind the buildings midway between streets. In still other cases, in closely built-up areas and particularly where the street is very wide or already paved, it may be advantageous and economical to construct laterals on each side of the street. Main, trunk, and outfall sewers should follow the most feasible route to the point of disposal. All sewers should be located outside of roadways as much as possible to reduce the number of roadway crossings. A sewer from one building should not be constructed under another building or remain in service where a building is subsequently constructed over it if any other practical location for the sewer is available. Where no other location is suitable, necessary measures should be taken to assure accessibility for future excavation and complete freedom of the sewer from superimposed building loads. The following safety precautions must be strictly observed in the sewer layout:

(1) No physical connections exist between sewer and water supply systems.

(2) Sewers and water lines will be at least 5 feet apart horizontally, except as permitted by TM 5-814-1, paragraph 6b.

(3) Where conditions require a sewer to cross above a water line, the sewer should be constructed of cast iron, steel, or other pressure pipe for a minimum of 10 feet on each side of the crossing and preferably with no joint within three feet of the crossing.

(4) At crossings of force mains or inverted siphons and water lines, the sewer shall be at least 2 feet below the water line.

b. Manhole Location.

(1) Manholes are required at the end of laterals and at each change in direction or slope. The distance between manholes will not exceed 400 feet for sewers less than 18 inches in diameter. For sewers of 18-inch pipe or larger and for outlets from sewage-treatment plants a spacing of 600 feet may be used provided that the velocity' is sufficient to prevent sedimentation.

(2) Manholes must be located before the rest of the design can be completed since the design method involves finding the pipe size and slope from manhole to manhole.

(3) Once the layout is determined and the manhole locations chosen, each lateral, branch, and main can be designed. It is probably easiest to start with the smallest sewers and work up to the mains.

c. Flow Rates.

(1) General. The flow rate between manholes will be the sum of (1) the flow into the upper manhole, (2) sewage from any house connections between manholes, and (3) infiltration into the sewer. It is assumed that this total flow will exist throughout the whole section of sewer between manholes. This is not strictly true if a house connection exists somewhere along the line (fig 4-8). The flow between manhole 2 and the place where the house connection meets the sewer is 125 gpm, plus some amount of infiltration which can be neglected. The flow in the sewer from the connection to manhole 3 is 155 gpm. Therefore, in designing the sewer from manhole 2 to manhole 3, 155 gpm is assumed to flow in the whole section. Three conditions may prevail:

(a) The flow in the house connection is small compared to the flow in the sewer. In this case, the effect is small and can be neglected.

(b) The flow in the house connection is large compared to the flow in the sewer. In this case, a change in pipe size or slope is necessary and a manhole must be used where the sewer and house connection meet.

(c) The flow is neither so small nor so large that a manhole is necessary. In this case, the sewer should be designed for both flow rates. If one pipe size at a given slope will give an acceptable velocity for both flow rates, then that design is acceptable for the complete sewer section. If one pipe size at the same slope will not give an accepta-

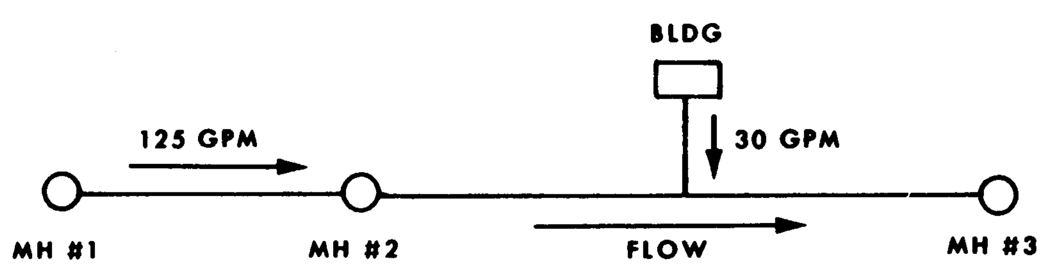

Figure 4-8. Plan view.

ble velocity for both flow rates, then either the pipe size or the slope must be changed at the house connection to the sewer and a manhole placed there.

(2) Quantity of flow. The peak sewage flow from a theater of operations facility is assumed to be 70% of the peak water demand for that facility. The peak flow from all facilities are assumed to occur at the same time. The peak flow in a sewer is the sum of the peak flows from all sewers and house connections discharging into it. Besides this flow, there will be some increase in flow due to infiltration. If nothing is known of the area, a figure of 2 gpm per 1000' of sewer may be assumed for infiltration. Of course, if any information on infiltration in the area is available from other sources (such as sewer systems already in operation nearby), then that value should be used.

d. Pipe Slope.

(1) The natural ground slope is usually used, as a first estimate for pipe slope, to minimize excavation. If this slope is unacceptable, either because it is too small or too great, will not provide an acceptable velocity, or does not meet cover requirements, a new slope must be chosen.

(2) The cover should be at least 2 feet over the crown of the pipe to protect the pipe from superimposed live loads of ordinary traffic and 4 feet for heavy trucks, or extra strength pipe or other pipe structurally capable of supporting the wheel loads with two feet of cover will be used (fig 4-9). All force mains should be buried to a depth such that the top of the pipe will be at the maximum frost penetration. Gravity sewers may be constructed with the bottom of the pipe at the maximum frost penetration when the minimum depths of burial (cover) specified above will not be violated.

(3) Often minimum cover requirements can be maintained by using drop manholes as indicated in figure 4–10, (1) If a standard manhole is used at 11, then a large slope shown by the dashed lines must be used. If a drop manhole is used at 11, then a much smaller slope can be used. This gives two advantages. First, the velocity will be lower between manholes 11 and 10 so there will be less scouring action in the sewer. Secondly, and most important, much less excavation will be required.

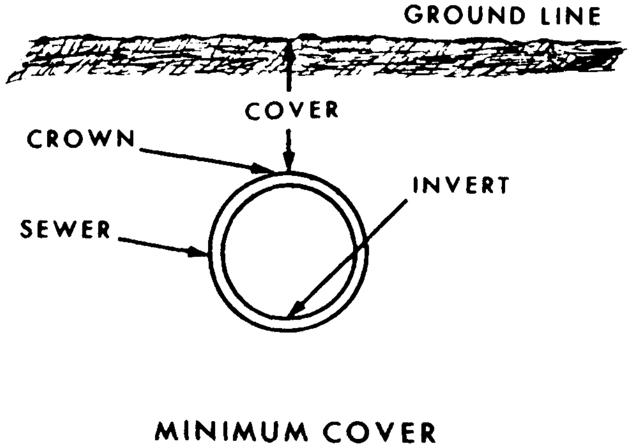

Figure 4–9. Minimum cover.

(4) As a second example, consider figure 4–10, (2). If a design such as this were used, the velocity in the sewer would be so high that the pipe would be rapidly scoured.

(5) Figure 4-10, (3) shows how the slope, and thus the velocity, can be decreased; however, an extreme amount of excavation is necessary.

(6) Figure 4–10, (4) shows how drop manholes can be used to keep both the slope and the excavation to a minimum.

e. Pipe Size.

(1) After a slope is chosen, the pipe size

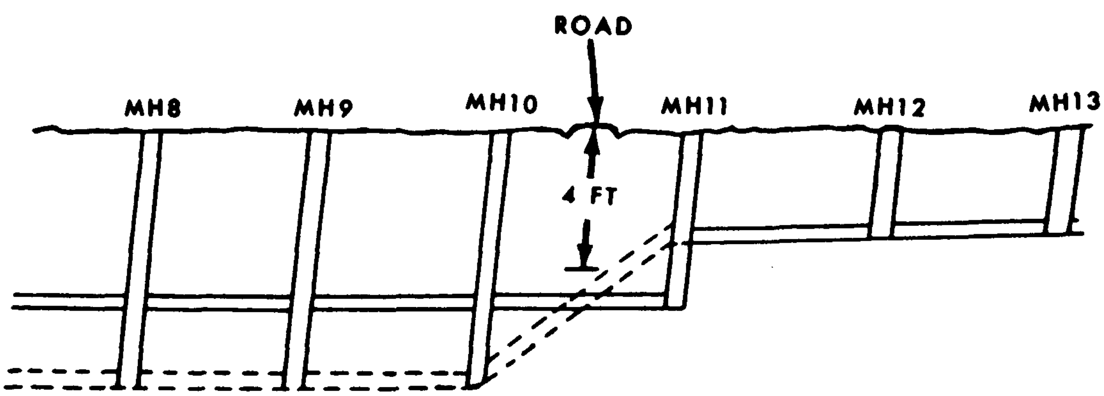

Figure 4–10. Use of drop manholes—(1 of 4).

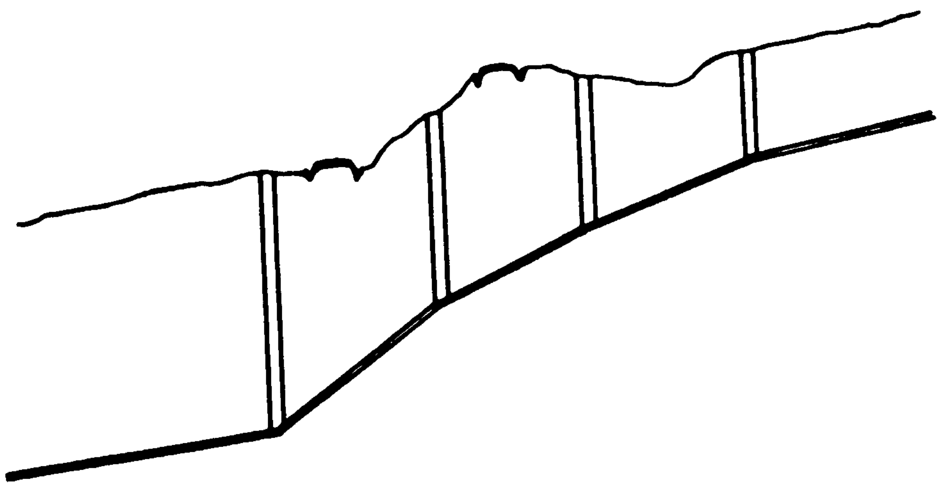

Figure 4–10. Use of drop manholes—Continued—(2 of 4).

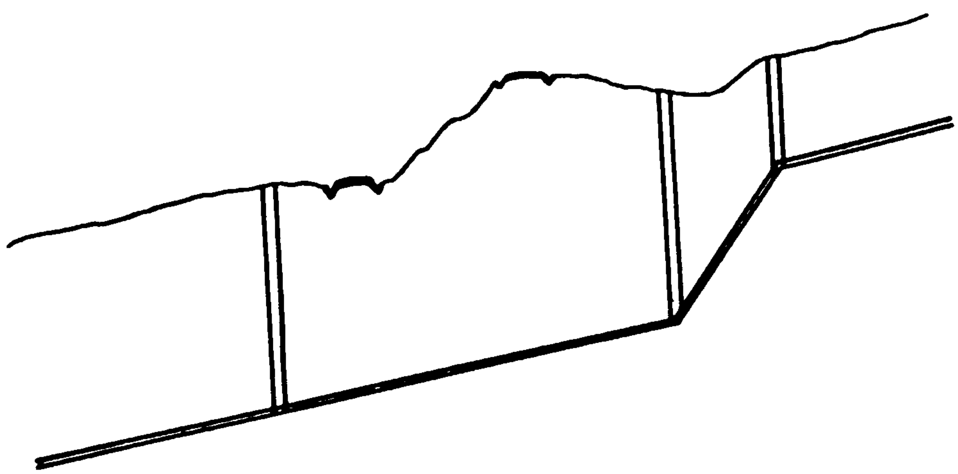

Figure 4–10. Use of drop manholes—Continued—(3 of 4).

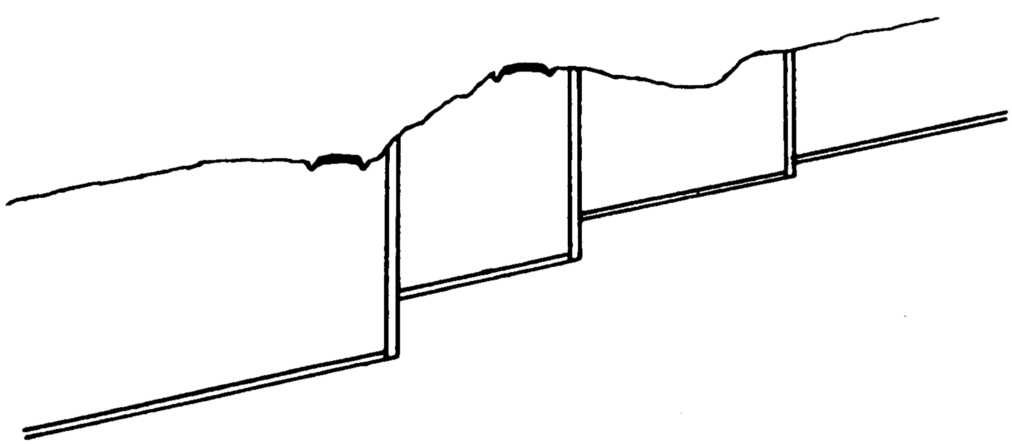

Figure 4–10. Use of drop manholes—Continued—(4 of 4).

necessary can be determined by use of formulas or charts. The formula that has had the widest acceptance among engineers for sewer design in the past is known as Kutter's formula. In the simplified form, usually used in design, it is—

$$V = \frac{\frac{1.81}{n} + 41.66}{1 + \frac{N(41.66}{\sqrt{R} +}} \sqrt{RS}$$

Where—

V = velocity in feet per second

n = a coefficient, dependent primarily upon roughness and, to some extent, upon size and shape of the conduit

R = hydraulic radius in feet

S = slope in feet per foot.

The Manning formula, which uses the same nomenclature and is much simpler in form than Kutter's formula, is-

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

(2) The results obtained by the two formulas are practically the same except that for pipe sizes smaller than 12 inches, the Manning formula requires larger values of n for comparable results. It is recommended that 0.013 be used as the value of n in Kutter's formula for all sizes of pipe and in Manning's formula for pipe larger than 10 inches, and that 0.014 be used in Manning's formula for pipe sizes of 10 inches and smaller. Figures 4–11 and 4–12, respectively, are pipeflow charts based on the two formulas using the values of n, as recommended. Either chart may be used to determine flow rates for pipes running full. MGD stands for million gallons per day; GPM is gallons per minute, and CFS means cubic feet per second. Along the top and bottom of the charts is slope in feet per hundred which is also percent. Inside the chart are lines moving up to the right. These lines are different pipe sizes and range in size from 4-inch to 48-inch diameter. The lines perpendicular to the pipe size lines are velocity lines and range from 1 foot per second (fps) to 12 fps. The pipe chosen must handle at least as great a flow at the chosen slope as the actual flow found in *c* (1) above. To find a pipe size which will do this, enter the chart on the left or right side at the actual flow rate. Draw a horizontal line until the chosen slope is intersected. The pipe size below this point of intersection is too small. The pipe above this point must be used.

(3) As an example, find a pipe size to handle an actual flow of 300 gpm at 1% slope. Use figure 4–11 for this example. Enter the chart at 300 gpm on the right and move horizontally to the left until the 1% slope line is intersected. The point of intersection is above the 6" diameter pipe and below the 8" pipe. Therefore 6" pipe cannot handle 300 gpm at a 1% slope and 8" diameter pipe must be used. The minimum pipe sizes which may be used for theater of operations construction are 4 inch diameter for a house connection and 6 inch diameter pipe for any other sewer.

f. Actual Velocity.

(1) The acceptable limits for the sewage velocity are 2 fps to 10 fps. Velocities lower than this will tend to deposit solids in the sewer and velocities higher will scour out the invert of the sewer. Occasionally, the designer must choose between using a lower velocity than 2 feet per second or of putting in an automatic lift station. If it can be shown that the costs incurred in keeping the sewer clean, and perhaps replacing it, are cheaper over the design life of the system than the procurement and maintenance cost of the lift station or other special facility, then the actual velocity may be decreased to 1.5 fps at peak flow.

(2) The actual velocity is found by the following six steps:

(a) Find the full flow. (Step 1) The full capacity of the sewer is found by entering the chart at the given slope and moving all the way up to the chosen pipe size. Moving horizontally to the right from this point the full capacity can be read. Continuing the example started above, the chart is entered at the 1% slope line. Moving up to the 8" line and reading to the right, a full flow of 500 gpm is obtained.

(b) Find the velocity of full flow. (Step 2) The velocity at full capacity is found by entering the chart at the design slope. Move up vertically until the design pipe size is intersected. (This point of intersection is the same point found in step 1 above). Through this point draw a parallel to the velocity lines. Knowing the velocity value of the line above and below, an estimate of the velocity value of the new line can be made. This is the velocity at full flow. For the example above the chart is entered at 1%. At the intersection of the 1% line and the 8" diameter line, a line is drawn parallel to the velocity lines. The new line lies between the line of 3 fps and 3.5 fps, and by interpolation is 3.2 fps.

(c) Calculate the discharge ratio. (Step 3) The discharge ratio is the ratio of the actual discharge (flow) (QA) to the full discharge (Q.).

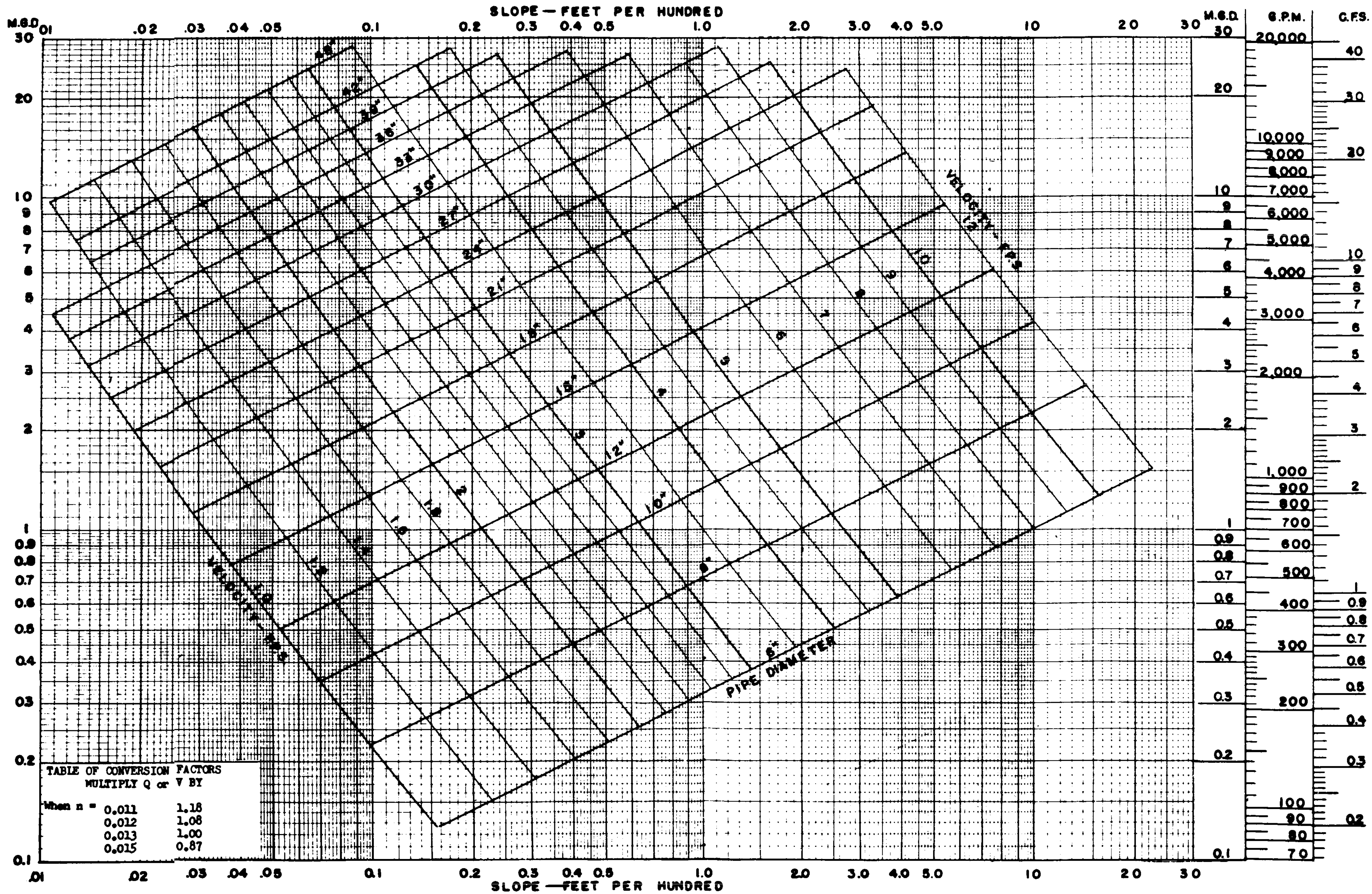

TABLE OF CONVERSION FACTORS MULTIPLY Q or V BY	
When n = 0.011	1.18
0.012	1.08
0.013	1.00
0.015	0.87

PIPE FLOW CHART
KUTTER'S FORMULA (N=.013)

Figure 4-11. Pipe flow chart—Kutter's formula.

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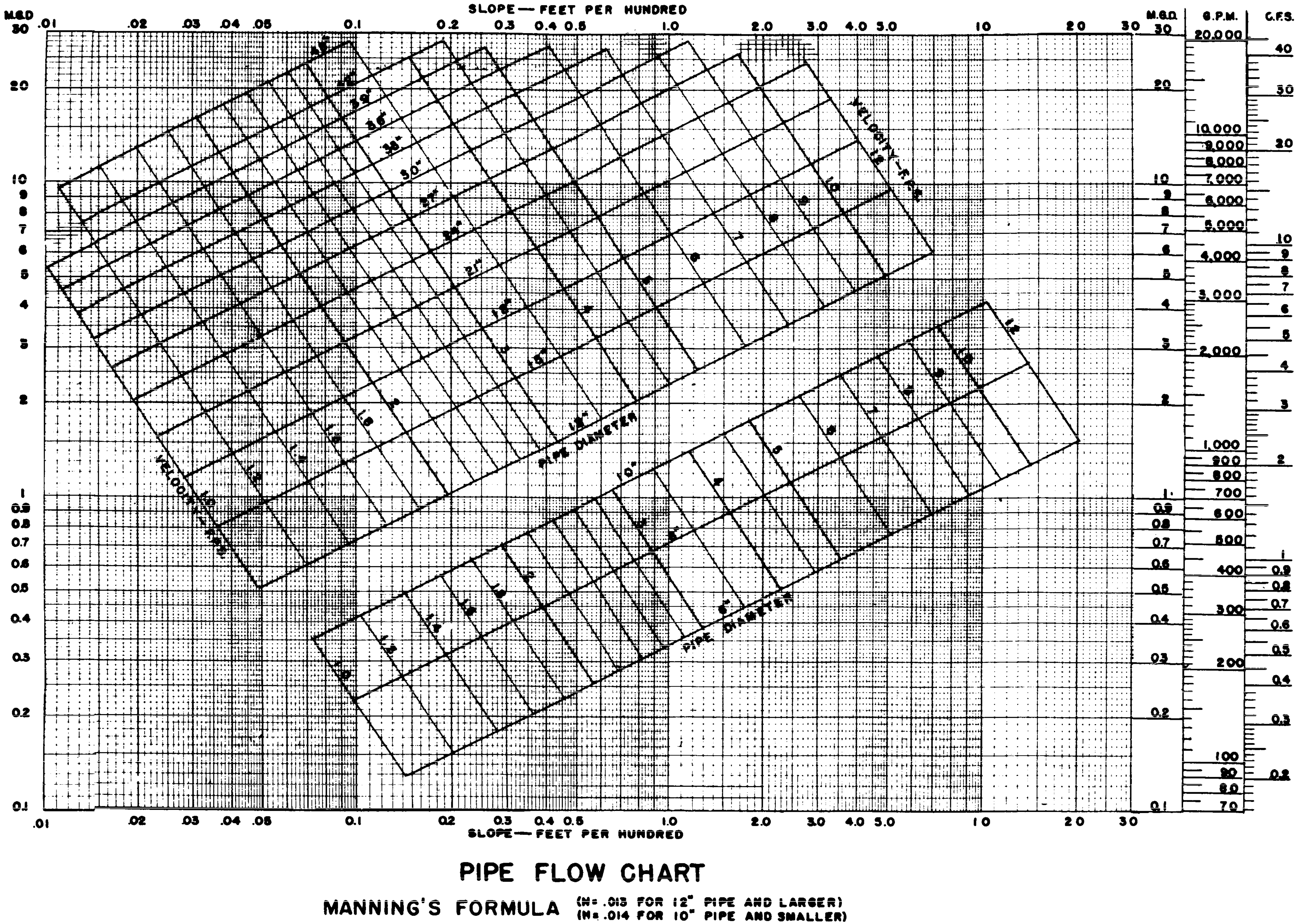

Figure 4–12. Pipe flow chart—Manning's formula.

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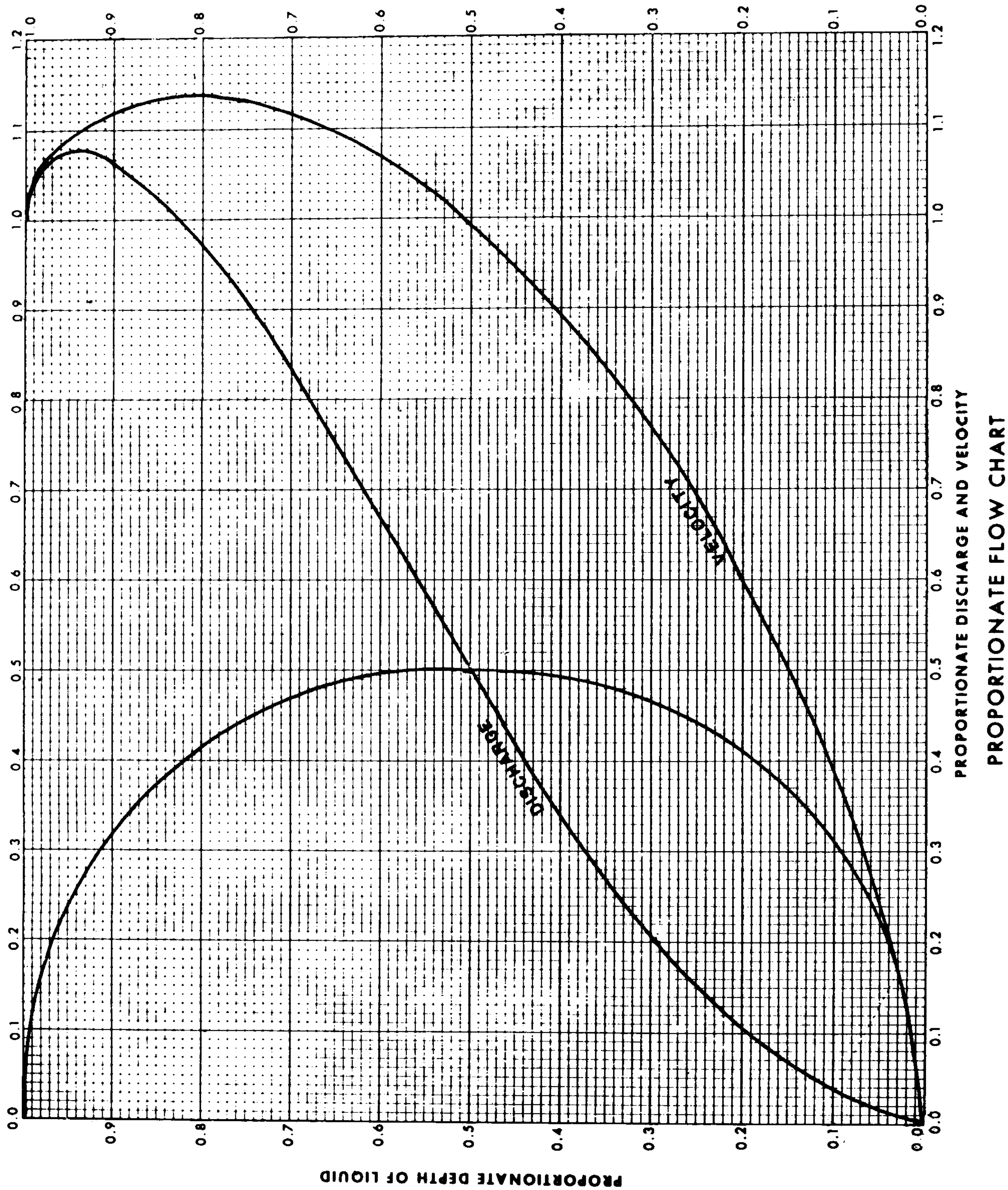

Figure 4–13. Proportionate flow chart.

Thus the discharge ratio is found by dividing the actual flow by the full flow. For the example started above, the actual flow is 300 gpm and the full flow is 500 gpm. Therefore, the discharge ratio is $\frac{300}{500} = 0.6$.

(d) Find the velocity ratio. (Step 4) The velocity ratio is the ratio of the actual velocity (V_a) to the velocity at full flow (V_c). The velocity ratio is found by the use of the proportionate flow chart shown in figure 4-13. The semicircle shown on the graph depicts a pipe cross section. This is used with the other two curves to show how the discharge and velocity ratios depend on the depth of the liquid in the pipe. The graph shows that the maximum velocity (velocity curve) does not occur at the maximum discharge (discharge curve) value. This is due to the fact that, at maximum discharge, the cross-sectional area of pipe being used is larger; therefore, the velocity losses due to friction are greater. The chart is used by entering along the top or bottom of the value of the discharge ratio. Move vertically along the discharge ratio value until the discharge curve is intersected. From this point move horizontally to the right until the velocity curve is intersected. At this point move vertically up or down and read the velocity ratio at the top or the bottom of the chart. Continuing the example, the chart is entered along the bottom at the value of ratio 0.6. Moving up to the discharge curve across to the velocity curve and down to the bottom a value of 1.045 is read. The velocity ratio is 1.045. The only case where this method of using chart 3 gives an incorrect answer is when the discharge ratio is 1.0. In this case, the actual velocity must be equal to the full flow velocity because the pipe is flowing full. Since the velocities must be equal, the velocity ratio is 1.0.

(e) Calculate the actual velocity. (Step 5) The velocity ratio is the actual velocity divided by the full flow velocity. Therefore, the actual velocity can be determined by multiplying the velocity ratio by the full velocity. Continuing the example, the full flow velocity was found to be 3.2 fps and the velocity ratio 1.045. Therefore the actual velocity will be (3.2 x 1.045) = 3.34 fps.

(f) Check the actual velocity. (Step 6) The actual velocity must be between 2 and 10 fps. There is a greater probability that suspended solids will settle and clog the sewer at velocities less than 2 fps. The sewage must be kept flowing toward the treatment facilities so it will not become septic. However, high velocities must be avoided to prevent scouring the sewer.

g. Determine Invert Elevations. Invert elevations can be determined once the slope is known. The elevation of the invert at the lower manhole is the elevation of the invert of the upper manhole less the product of the slope multiplied by the length of the sewer between manholes. The invert elevations of the upper manhole will be known for each section except the first. The invert at the first manhole will usually be made as close to the ground level as possible while still maintaining minimum cover (fig 6-4).