STORM SEWER DESIGN

THESIS FOR THE DEGREE OF C. E.

HOWARD DANIEL SEVERANCE

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INTRODUCTION.

The subjects of drainage and sewerage are so intimately associated as to be almost inseparable. In general,however,it may be stated that while the subject of sewerage refers principally to the removal of excremental or human waste and other refuse matter common to human habitations,the subject of drainage properly relates to the removal of storm-water from the surface and subsoil.

All water given by rain storms may without impropriety be called storm-water. This name,however,is commonly applied to water from rain storms that does not soak away immediately into the ground nor evaporate,but flows away over the surface through natural chanels or artificial conduits..

Sewers may be designed to carry storm-water alone,house refuse alone,or both. Those that carry storm-water alone are called Storm Sewers,those that carry human refuse alone are called Sanitary Sewers and sewers which carry both storm-water and human refuse are called Combined Sewers. A storm-sewer system should be adequate for the prompt removal of the rain fall from the surface during violent storms,including such animal and vegetable refuse from the streets as will necessarily be removed with the storm-water.

The separate system should be built to carry off promptly from houses all sink,laundry and closet wastes without offensive odors and without interruption. It should keep itself clean, that is, free from deposits. It should not pollute the soil through which the pipes pass and it should have an outlet that is without objection.

While it is not the purpose of this paper to treat the subject of sanitary sewers or combined sewers, it seems necessary to set down some of the advantages and disadvantages of combined systems since the question as to which is best to install confronts the engineer in a large percentage of the cities he is called upon to investigate in reference to the matter of storm sewers.

During the past twenty-five years great progress has been made in the matter of sanitation, not alone from the standpoint of engineering and the general advancement in sewer construction, but in the public mind generally there has been driven home the fact that sewers are an absolute necessity to the health and comfort of the community. This campaign of education has been carried to such an extent that it is found necessary by persons desiring to place subdivisions and additions on the market in the shape of town or city lots, to see that their subdivision or addition is properly sewered before offering the same for sale. It is indeed difficult to prophesy the good effect of such a spirit even within the next ten years. This condition is mentioned because in the light of what is to follow it will be found that the real necessity for storm sewers does not occur until considerable time, perhaps years, depending upon the rapidity of city growth, after the sanitary sewers are in place. In general the

following facts should be considered in case the town or city, or portion thereof under consideration has not any adequate sanitary sewer system. If it has such a system it is good policy to leave it alone and plan a separate storm sewer system.

1st. Sanitary sewage, which constitutes the dry weather flow alone in combined sewers is so very small in comparison with the storm sewage that in circular sewers, which are the most eonomical to build, it forms merely a trickling stream with little velocity over the bottom of the large sewer required. This condition can be overcome in a small degree by the installation of the egg-shaped type of sewer, which can be made of such a shape as to be self-cleaning even with a small amount of flow. Moreover, sanitary sewers are free from sand and other debris which are inevitably washed into combined sewers during storms and these are especially troublesome in forming deposits. Hence in the separate system generally it is easier to keep sewers free from deposits.

2nd. Above the low-water line in combined sewers the extensive interior surfaces of the large sewers required become smeared with filth in time of flood which remains to decay and produce foul gases after the flood subsides. This coating is not considered by some to be dangerous. However, it is a very important factor to be taken into consideration in the designing of the combined sewers.

3rd. On account of the comparatively small size of the sanitary sewers in the separate system it is easier to flush them so as to keep them clean. Automatic flush tanks can be used at small expense to do this very satisfactorily. The combined system absolutely precludes the possibility of using the automatic flush tank.

4th. On account of the comparatively small size of the sanitary sewers of the separate system the air in them is more frequently and completely changed by the daily fluctuation in the depth of sewage and by currents of air from ordinary ventilation openings. Hence in the separate system ventilation is easier and more perfect. However, in the combined system there is a larger volume of air over the sewage and this dilutes the gases to such an extent that they are claimed to be harmless.

5th. In case the sewage has to be purified the separate system is more economical because only the sanitary sewage need be treated, the storm sewage being discharged into nearby water courses.

6th. In small cities and in large portions of large cities the storm water can be usually carried some distance in the gutters and then removed by comparatively short lengths of storm sewers laid at shallow depths and discharged into the nearest suitable natural water courses. In such cases a separate system of sewers will usually cost only a fraction as much as a combined system. For small towns the great cost of a combined system would either prohibit the construction of sewers entirely or postpone it indefinitely, were it not that a separate system can be built so cheaply. On this account alone the introduction of the separate system of sewers has been of incalculable benefit to smaller cities of America.

7th. On account of their relatively small size, sewers of the separate system can be made almost entirely of vitrified sewer pipe, which has the important advantages over brick sewers of greater smoothness, of being impervious, of having few joints, and of ease in making the joints practically water tight.

8th. Often a combination of the two systems can be made to advantage, storm-water being admitted to the sewers only in certain portions of the system, such as the business district.

9th. As will be shown in the following, storm sewers are not usually designed to take all of the storm-water in case of extreme storms because in such instances the cost would be prohibitive. In the combined system it would be necessary to make sewers to take such storm-water in addition to carrying the sanitary sewage flow because in the event of a sewer overflowing great damage would be wrought to property and the health of the community endangered.

It is to the considerations stated above that the popularity of the separate system and its adoption in many of the smaller cities is due. It is, moreover, preferable where the sewage has to be pumped or purified. Whether or not it should be adopted for larger cities is a matter depending upon local physical conditions and economical considerations.

In the following pages the subject of storm sewers will be treated with only an occasional reference to combined or sanitary sewers.

It is found possible to treat the subject in general terms only, owing to the fact that the basic assumptions to meet different local conditions are so greatly varied. It is the earnest desire of the writer to impress the need of careful considerations of economy throughout the work, from the first assumptions to the final details of construction, for the real worth of an engineer is finally reckoned on the basis of the amount he can save a city or community instead of the amount he expends for it. Unfortunately, however, his pecunary compensation is, in most cases, computed on the latter basis.

Economy is not here used to mean the curtailment of the necessary, but the elimination of waste and the unnecessary so far as possible.

The subject will here be treated under the following general topics:

PRELIMINARY INVESTIGATIONS AND DATA.

FINAL ARRANGEMENT OF DATA WITH GENERAL HINTS IN THE MATTER OF MAKING BASIC ASSUMPTIONS.

METHOD OF COMPUTING SIZES OF SEWERS.

TYPES OF SEWERS AND MATERIALS OF CONSTRUCTION.

APPURTENANCES.

The plates and illustrations appended hereto were prepared in the study of a particular problem, although some of them are of general application. Their principal value in this work lies in the possibility that they will suggest similar forms and methods.

PRELIMINARY INVESTIGATIONS AND DATA.

Before attempting to formulate any plan for a storm sewer system the entire territory under consideration and such adjoining areas which may form a part of or be drained by the same system should be carefully studied. A typographical map of the city and adjoining territory should be made. This map should be on a scale between 200 and 400 feet to one inch,depending upon the size of the district under consideration. For undulating ground the contour interval should be 5 feet:for flat ground 1 foot. A convenient way to proceed is first to make a map of the area on tracing cloth,showing the elevations,contours,and everything else that is to be shown on the final map,except special and derived data and the sewers themselves. White background prints can be made from these tracings and upon them the different classes of data can be placed and the plan developed roughly in pencil. In developing plans it is convenient to make figures directly on the map as the work progresses and perhaps several alternate plans may be carried to completion before a final choice is made. Such data as character of soil,subsoil, percentage of impervious coverings,street grades with direction and rate of fall,character of pavements,number of persons per acre,etc.,should be shown in reference to each block within the district. Natural water courses and every possible point of outlet should be located and studied in reference to their availability in working out a system.

A careful study should be made of the general economic conditions in the city,the resources and rate of growth parti-

cularly. This data will furnish a cue in predicting the probable future developments, with a fair degree of accuracy if compared with the history of growth in neighboring cities similarly situated. It is a wise precaution to avoid local real estate dealers while drawing conclusions on the subject of probable future growth.

In this connection it may be said that engineers as a rule, though there are many notable exceptions, prophesy conditions which are unatainable within any reasonable length of time and in consequence assume conditions which fix the ratios of maximum run-off considerably higher than economic conditions warrant. This is probably due to the fear of popular criticism and a response to the clamor "Get the size large enough", "Err on the side of safety", etc. It is preferable to err on the side of safety, if at all, but not too much.

The probability that a district now unimproved may in future become thickly populated and consequently highly improved also carries with it the certainity that realty values in this district will increase many fold and can more easily stand the assessment at that time necessary to increase the capacity of the storm system than under present conditions. Besides, this there is the interest factor which has to be reckoned on the cost of unused capacity which in some instances within the writer's observation would in the course of twenty years pay for the complete installation of a parallel auxiliary sewer system that would more than meet the increased demand of such growth.

In determining the required capacity of a storm sewer one of

the most important conditions to be considered is the maximum rate of rain fall, that is the maximum rate per hour of precipitation during any given number of minutes. A knowledge of this condition is necessary to determine the amount of stormwater reaching the sewer during a storm continuing for a period of time equal to the time of concentration.

The records of rain fall are rather incomplete. Records of daily, monthly and yearly rain fall are numerous, but useful as such records are for some purposes they have little value for the design of sewers. The records of storms as generally reported, give the total precipitation for the entire storm and probably the duration of the storm, but they do not give the maximum rate of the precipitation. The average rate of precipitation throughout the storm can be obtained by dividing the total precipitation by the duration of the storm, but this will seldom if ever be the maximum rate of precipitation, for, as is well known, the greatest intensity of rain fall is attained only during short periods. It is often the case that a rain storm will continue for several hours with a very uneven intensity - sometimes a mere drizzle and sometimes a heavy downpour. Evidently the total precipitation of such a storm will bear no relation to its maximum rate. A storm that will give four inches of rain in twelve hours, may give two inches in two hours, or probably one and one-half inches in thirty minutes. The average precipitation during the storm would then be at the rate of four-twelfths or one-third inch per hour while the average precipitation during the thirty minutes would be at the

rate of one and one-half divided by one-half, or three inches per hour.

A locality subject to long-continued drizzling rains may have a large annual rain fall, while very heavy rains may occur in localities having much smaller annual rain fall. It is this maximum rate, or rapid downpour during a reasonably short period that most severely taxes the capacity of a storm sewer. The general condition to be considered therefore in designing a sewer of this kind is the maximum intensity of the precipitation, that is the maximum rate per hour during a period of time sufficient for the water from the most remote parts of the district to reach the sewer and flow through the sewer to the point under consideration. This last statement is somewhat general and may be varied by shape of the district under consideration.

It is evident that in order to design intelligently a storm sewer the designer should have a reasonably accurate record of the rain fall in the locality giving both the rate and the duration of the various degrees of precipitation for each storm. Such records are obtainable by means of self-registering rain gauges in which the continuous amount of rain fall is automatically recorded on a chart moved by clockwork. In 1889 the United States Weather Bureau placed self-registering gauges in the principal American cities. Most valuable information relating to the rain fall is given in the Weather Review, the official publication of the United States Weather Bureau. Only the records of self-registering gauges, however, can be considered as really accurate.

One important condition indicated by the data obtained by means of the self-registering rain guage is that the maximum precipitation for a short period of time is reasonably uniform throughout the United States. There is,however,some slight difference in the rate of rain fall in different sections. The Southern Coast States,for instance,show a higher rate of maximum rain fall than those of the interior and it is also found that certain mountainous districts also have a much greater rate of maximum rain fall than the more level sections. The rates of rain fall along the Pacific Coast show considerable variation owing to the proximity of the Coast Range and the Sierra Nevadas. Generally it is well to take the nearest available data that can be furnished by the United States Weather Bureau and make careful study of the comparative total rain falls in that city and the district under consideration.

Rainfall data obtained from the nearest available source should be collected and carefully tabulated,a convenient mode being to set down the rates in vertical columns under their respective duration periods.

FINAL ARRANGEMENT OF DATA WITH GENERAL HINTS IN THE MAKING OF BASIC ASSUMPTIONS.

All data appertaining to the existing conditions as above referred to relating to the sections of the City which are now improved and moderately well built up, should be entered upon the preliminary map. Upon this should also be placed in the unimproved districts the assumed conditions, that is, the conditions which the storm sewer will be expected to meet within the next forty years. Preliminary sewer location may then be made in red ink together with the approximate grade and this sewer location should extend as far as the requirements of the city to meet the above assumptions, that is to say, when the city is finally built to the limits the plan outlined upon this sheet should answer the requirements at that time.

Drainage areas should be marked in ink. Adjoining drainage areas may be marked with different colored crayon so as to distinguish them. The areas of these drainage areas should be computed and placed in their respective places together with the actual and assumed percentages of impervious surface in each. The density of population indirectly affects the quantity of storm-water flow since it naturally follows that the denser the population the greater percentage of impervious surfaces. Some authors have suggested a ratio between the population per acre and the percentage of impervious surfaces. Such deductions are gathered from a large number of observations and are consequently of a general nature serving as guides rather than laws of procedure.

The results of such investigations show that the percentage of impervious surface is numerically equal to the number of persons per acre in residence districts. This ratio is not true when the density of population exceeds sixty per acre, because beyond this the percentage of impervious surface does not materially increase. This suggests the problem of future growth upon which there has been a great amount of discussion by many eminent authorities. Vain attempts have been made to lay down general laws relating to city growth but it seems that each community has its own mysterious "rule-of-the-thumb" method of growing.

There are some very general hints which coupled with considerable sound judgment will give results accurate enough for the problem at hand.

Study the city carefully with a view of classifying same. For instance, is it a commercial center, a manufacturing center, a resort town, or a suburban residence section. Study the history of its growth and ascertain the agencies which have promoted it. Make comparison with the history of growth of cities similarly situated and having resources of a similar nature.

Just how far into the future it is necessary to prophesy to handle the problem with greatest economy is a question upon which there is some diversity of opinion, but in the opinion of the writer, as above indicated, forty years is an outside limit even for rapidly growing cities.

After determining upon the probable density of population based upon future growth, percentages of impervious areas can be

computed as above indicated and placed upon the sections now sparsely settled and unpaved.

The selection of route for main storm sewers is a matter requiring careful study in order that the most efficient and consistantly economical location will be made.

In general the sewer should follow the lowest portion of the drainage area under consideration, it being found economical and sometimes absolutely necessary to cross private property where deep valleys intersect the streets at irregular intervals. The cost of sewers is greatly increased when they are built over unstable ground and therefore the character of the soil and subsoil should be carefully investigated and bad spots avoided if found possible and economical so to do.

The particular location in streets, that is the particular portion of the street to be occupied by the storm sewer should be such as to avoid damaging sanitary sewers and their laterals, water and gas mains and other permanent structures, due precaution being taken to avoid excessive cuts. The writer has in some instances found that the most economical location was the center line of the sidewalk in residence sections. At others as near the center line of the street as possible, keeping above and parallel to the sanitary sewer, at one side or the other of same. When the location is made in sidewalks less depth of earth and other material over the sewer is necessary than when the location is made in the roadway portion of the street. Plate I shows a location of main sewer. The final location to meet the present needs is shown in full line black ink. Proposed extensions to meet future requirements are shown dotted. The alternate location, abandoned because of economical conditions, is shown in red ink. This is mentioned merely to indicate that in the final location of storm sewers economical considerations are really paramount.

Some working equation for rate of rain fall or curve showing the relation between the rate of rain fall and duration of storm is of prime importance to the designer.

A general form of equation widely used and highly recommended by best authorities is:

$$r = \frac{a}{t + b}$$

in which r is the rate of rain fall in inches per hour, t is the duration of storm in minutes and a and b are constants.

The selection of values for a and b may be made by plotting on cross-section paper, the records of storms of various durations taken from data obtained and tabulated as indicated in the discussion of "Preliminary Data", and selecting typical maximum values of rate "r" at various corresponding values of duration "t".

Then substitute these corresponding values of r and t in the above equation as constants. The values of a and b, treated as unknown quantities can then be calculated from any two such equations, considered simultaneously, as follows:

Assuming that r_1, t_1 and r_2, t_2 are corresponding values for r and t,

then $$r_1 = \frac{a}{t_1 + b} \quad \text{and} \quad r_2 = \frac{a}{t_2 + b}$$

from which $a = r_1 t_1 + \frac{r_1 (r_2 t_2 - r_1 t_1)}{r_1 - r_2}$

and $b = \frac{r_2 t_2 - r_1 t_1}{r_1 - r_2}$

The general relation between a and b is approximately such that $b = 1\frac{1}{2}\sqrt{a}$.

The following values for a and b are suggested by Prof. A.N.Talbot:

For rare storms	$a = 360,\ b = 30$:
For occasional storms	$a = 200,\ b = 20$:
For ordinary maximum storms,	$a = 105,\ b = 15$.

After determining the proper value of these constants a working equation can be made and a curve, similar to Plage II, drawn for convenient reference.

The ordinates give the rate of rain fall in inches per hour corresponding to the duration of storm shown along the abscissa. This curve was designed for a particular locality in which there may be storms whose rates will exceed those shown by this curve, but the probability of their occurrence is estimated as once in ten years.

The rain fall in cubic feet per second per acre corresponds almost exactly, or close enough for all practical purposes, to the rate of rain fall in inches per hour. It is safe to assume that total precipitation in cubic feet per second per acre equals the rate corresponding to the duration of storm. The chart shown on Plate III is derived from the preceding curve and the equation therefor. The ordinates OY on this sheet represent the area to be drained in acres, the abscisse OX the total amount of precipitation in cubic feet per second. The lines 0 - 5, 0 - 10, 0 - 15, etc. are the loci of points whose ordinates are, area and total precipitation, corresponding to the times of concentration, five minutes, ten minutes, fifteen minutes, etc., respectively. To find the total precipitation on a given area, say four acres, corresponding to the time of concentration of say twenty minutes, proceed horizontally from the ordinate four to its intersection with the vector 0 - 20, thence downward vertically to the abscissa 0 - X, which will give the total precipitation in cubic feet per second as twelve. This chart is a specially derived one and is found to be very convenient for checking off results of analytical computation.

METHODS OF DETERMINING SIZE OF SEWER.

When rain begins to fall upon an area drained by a storm sewer the water falling in the immediate neighborhood of the outlet at once enters the sewer and begins to be discharged. As time passes and the rain continues water arrives at the outlet from the more remote portions of the drainage area and the discharge at the outlet increases quite rapidly until water is being discharged from all portions of the drainage area at the same time. After that any further increase is slow, being due only to a percentage of run-off slowly increasing as the saturation of the soil becomes more complete.

The time of concentration is the longest time required for water from the remotest portions of the drainage area under consideration to reach the outlet of that portion. For general considerations the storm causing the greatest rate of discharge in a storm sewer will be the maximum storm lasting a length of time equal to time of concentration. If a time less than this be taken the water will not be discharged at the outlet from all the points of the drainage area at once and that very near the outlet will have a chance to run away before that from the remotest point arrives. On the other hand, if a time be taken longer than the time of concentration the heaviest rate of the maximum storm lasting this long will be less than the rate of the maximum storm lasting a length of time just equal to the time of concentration, and since the storm is lighter the flow will be lighter.

Not all the water falling in a drainage area will be carried away in the sewer. During and after the storm some of the water evaporates into the air and some is absorbed into the soil. Some also collects on the surface to flow on into the sewer after the storm is ended. The engineer determines the percentage of rain flowing off in the sewer by estimating the maximum percentage of run-off of the drainage ares.

The general method of calculating the amount of storm sewage for any particular drainage area is as follows:-

(a). Calculate the time of concentration or longest time of flow to the point for which the size of sewer is to be determined.

(b). Calculate the maximum rain-fall corresponding to the time of concentration.

(c). Calculate the percentage of impervious and pervious area on the water shed drained by the sewer.

(d). Using the percentage of impervious and pervious areas obtained as above,calculate the maximum percentage of run-off or the percentage of the rate of maximum rain fall which will be running off in the sewer under design at the end of the time of concentration.

(e). Calculate the total maximum rate of flow of storm sewage by multiplying together the drainage area, the maximum rate of rain fall corresponding to the time of concentration, and the maximum percentage of run-off.

(a). The time of concentration may generally be divided as follows:

1. The time required by the water from the roofs and yards

to reach the pavements or the gutters.

2. The time required to run along the gutters to the inlet and the sewer, and

3. The longest time required for the water to flow through a line of sewers to the point for which the size is to be calculated.

1. The time required for water to reach the gutters may usually be estimated between five and ten minutes, depending upon the slopes and surfaces and also upon the density of the population. In thickly built up sections the rate of run-off from yards, roofs, etc., may be taken at the lower rate while sparsely settled portions of the city, with flat surface slopes may be estimated at ten minutes or even higher.

2. Time required for water to flow along the streets and gutters to the sewer may be calculated from the formula $v = c\sqrt{s}$ in which v is the velocity in feet per second, c is a constant depending upon the character of the surface and s is equal to the fall in feet per hundred feet. Plate IV shows the curves for different types of surfaces and is useful in determining velocity for various percentages of slope. These curves will also be found useful in obtaining velocities of flow over outside and undivided areas which are tributary to the system.

3. The time required for water to flow through the sewers to the point of consideration should be computed by means of Kutter's formula, or by reference to the curves of velocity and discharge on Plate VI appended hereto. For exact determinings, however, the velocities, flowing full, are a little too low

as will be seen by reference to Plate VII showing the relative values of velocity and discharge for different depths of flow. In this plate the three curves represent, respectively, the relative values of the areas of wetted cross-section, of the velocity and of the discharge for different depths of flow, the value for the full depth of flow being taken as unity in each case. For any depth of flow the value given by the area curve multiplied by the valuegiven by the velocity curve will equal the value given by the discharge curve. The relative value given by the curves of the diagram are for a uniform slope provided they all relate to the same slope. The curves of velocity and discharge are necessarily only approximately exact, but they are sufficiently accurate for all ordinary computations. All the curves on the diagram relate to circular sewers. Kutter's formula is used in all the computations in this paper and computations are usually made on the basis of the sewer flowing full. However, sewers rarely discharge at their full capacity and in practise should not be designed so that they will do so. The velocities that are shown in the diagram will not be the usual velocities, but will bear a relation to the actual velocities that can be ascertained according to the depth of flow. This curve is particularly useful in determining the time of concentration because it shows that the values given by Kutter's formula when the sewer runs full really are not maximum and hence the time of concentration would be too long if such formula were used without regard to the maximum velocity possible to attain in a circular sewer.

(b). In calculating the maximum rate of rain fall corresponding to the time of concentration substitute the time of concentration t, as obtained by the above method in the equation for maximum rate of rain fall or use the element t as an argument in using the curve plotted from the same equation, which will give directly the value of rate of rain fall corresponding to that particular time of coneentration. A chart similar to that shown on Plate III may be used to advantage at this point to obtain the total precipitation in cubic feet per second on the area under consideration corresponding to the computed time of concentration. Select the nearest time vector or interpolate if necessary and proceed as explained in the preceding section.

(c). The percentage of impervious area may be calculated in the following manner: Take a typical unit of area, usually an average block having different percentages of imperviousness as follows:-

Roof area. From the average size of buildings and the average number of buildings per block actually in existence or assumed to meet the conditions of further growth, which will be connected with the sewer, or with the gutters, Calculate the total roof area in the block. Take this at its full value if the roofs are connected with the sewers, but only ninety per cent if the roofs are connected with the gutters.

First-class pavements. Calculate the total area per block of bricks, asphalt and stone block with tight joints and take eighty per cent of this area.

Second-class pavements. Calculate the total average area per block and take sixty per cent.

Third-class pavements. Calculate the total average area per block of good macadam and similar pavement and take forty per cent.

Hard earth roads. Calculate the total average area per block of the traveled hard earth surface and take twenty-five per cent.

Sidewalks. Calculate the several total average areas per block of first,second and third class sidewalks corresponding to the classes of pavement as above and take the same percentages as for the corresponding classes of pavements,namely eighty, sixty and forty per cent for first,second and third class sidewalks respectively. But if the pavements are separated from the gutters by side parkings,as in some city residence districts,take only one-half of the above percentages.

Finally add together all the rated average areas per block obtained as above explained and divide the sum by the total area of the typical block. The quotient will be the percentage of impervious area. The percentage of pervious area is obtained by subtracting the percentage of impervious area from one hundred per cent.

Another method which gives excellent results and is almost indispensable,in case the approximated future conditions are considerable in advance of the present,is to use the population per acre,actual or estimated,as a basis for estimating the percentage of impervious surface.

The rule that the percentage of impervious surface is equal, numerically, to the number of persons per acre will give results consistent with the accuracy of other assumptions necessary in the general problem.

(d). Calculation of maximum percentage of run-off. As before stated, not all of the water or rain falling on the impervious area of a water shed will run off during the storm. More or less amounts are evaporated or absorbed at once for no surfaces are absolutely impervious. A large amount goes to fill up small depressions in the surfaces, a still larger amount accumulates on the surfaces of the water-shed making its way toward the sewer. The amount so accumulated and its rate of movement increases, as the storm continues at the same rate, until finally an equilibrium of flow is established and the rate of run-off from the impervious area becomes practically one hundred per cent of the rain fall; that is, the shorter the storm the less per centage of run-off, and hence the sewer water-sheds having smallest time of concentration are likely to have the smallest per centage of maximum run-off. The maximum downpours which determine the size of the sewers, are often preceded by lighter downpours which saturate and partially flood the water shed, hence it will probably never be reliable to assume less than seventy-five per cent as the percentage of the maximum run-off from the impervious area of a sewer water shed even for short times of concentration and comparatively little damage from over-charged sewers. With longer times of concentration, say forty-five minutes or over, ninety-five per cent of maximum run-off from the impervious areas should be assumed. In the case of long-continued storms pervious areas become gradually saturated until some run-off occurs from it also. In case of storms lasting for several hours, such as caused the great floods in the rivers, this percentage of maximum run-off may be quite high, but for sewers the time of concentration and hence the duration of the maximum downpour are comparatively short, rarely longer than one hour.

The above statements are necessarily quite general in their nature, since it is impossible to lay down any fixed rule for obtaining the percentage of run-off. Careful study of local conditions and close observation of conditions of streets and existing sewers during storms are necessary links in the data chain.

Localities which are subject to long continued rains, that is, such as will completely saturate the ground, will produce a higher percentage of run-off than the contrary. The texture of soil and subsoil and general slope of the ground still further varies this percentage value.

The writer has prepared a chart shown on Plate V, which serves to illustrate the relation of percentage of maximum run-off to duration ofstorm for a few different typical conditions.

The ordinates show the percentage of run-off and the abscissae the duration of storm corresponding to the computed time of calculation.

The upper curve marked "Impervious surfaces" represents as near the actual values as can be obtained from considerable observation and best authorities.

The three other curves are typical and may or may not have practical application to a particular problem. However, they illustrate the generally accepted proposition that the percentage of maximum run-off from pervious surfaces bears a direct ratio to the time of concentration.

It must be borne in mind that the percentages given by this chart are not the percentages of run-off for the entire surface but percentage of the percentages of the various classes of surface. For instance, if there be forty per cent of the surface impervious and the remaining sixty per cent pervious, (hard soil, steep slopes) and the time of concentration twenty minutes, the total percentage of run-off would be

$$.86 \times .40 + .13 \times .60 = 42.2\%$$

of total precipitation running off during the time under consideration.

(e). The total effluent or maximum rate of flow of storm sewage at the point on the sewer line under consideration is the continued product of; (1) the area in acres, of the district drained by the sewer at that point, (2) the maximum rate of rain fall, in inches per hour, corresponding to the time required for the water to reach the point under consideration from the most remote portions of the district, and (3) the maximum percentage of run-off.

The proper size of sewer to carry the quantity of water as above calculated at the grade which the sewer will have leading away from the point under consideration may be computed from Kutter's formula.

Plate VI shows a graphic relation between the size, grade and discharge of circular sewers running full. This was compiled by using Kutter's formula and assuming the coefficient of roughness N = .015 which is a safe value for brick or concrete construction. The values given may be reduced so as to give values of velocity and discharge for N = .013 by adding nineteen per cent to the values taken from the curves.

TYPES OF SEWERS AND MATERIALS OF CONSTRUCTION.

Plate VIII shows three common types of sewer-section, namely, the circular, egg-shaped and the U-shaped. Upon the same plate will be found the relative values for area and velocity of discharge. The circular type of sewer is an old favorite because of its simplicity and because of the economy of its construction. The egg-shaped type is used for combined sewers in which there is a small dry-weather flow, a smaller amount of flow giving a higher velocity than in a circular sewer. The U-shaped sewer is recommended for size not over forty-two inches that is forty-two inches in greatest dimension. As seen from the characteristics of this type it has a higher velocity and discharge value than a similar size of circular or egg-shaped sewer. It is a good type to use where the sewer is placed under the sidewalks, with small head room.

Special cross-sections are sometimes found necessary for large sewers, of which there are a great many varieties used in the various cities of the United States and of Europe.

In general the selection of type of section depends upon the grade, location and quality of sewage to be carried.

The writer has found it economical to select and specify several different types of construction which he considered equal in efficiency and to use the type found to be lowest in cost of installation. This method has a further advantage of stimulating competition. The engineer may find that this cannot be done in some cases where a particular type may prove the most economical even though the first cost is somewhat higher.

Materials of construction for storm sewers are, vitrified pipe, stone, brick, and concrete.

Sewers twenty-four inches in diameter and under are usually built of vitrified sewer pipe. This material has a smaller coefficient of roughness than any other. Care should be taken, however, in the use of vitrified pipe to see that provision is made for the removal of sand and other damaging detritus, especially where the sewers discharge under high velocities. The writer has noted several sewers laid of this material and has found in some instances that the sewers have been cut nearly through in the short time of five years.

Stone was formerly used in the construction of sewers to considerable extent, especially in the large sewers. On account of its high coefficient of roughness and the high cost of good stone masonry this material is rarely used in modern times.

Brick is a favorite material for sewers too large to be made of pipe. The dividing line is usually drawn at thirty to thirty-six inches. Brick present many advantages for sewer work, including their moderate cost and their durability and their small size and regular shape, which enable them to be handled readily and used in building sewers of any desired cross-section with comparatively smooth and true interior surfaces.

Sewer brick, as those suitable for sewer construction are commonly called, should be harder burned than ordinary building brick to enable them to stand the wear from the flow of sewage and to insure against disintegration. They need not, however, be as hard as No.1 paving brick and hence constitute an intermediate grade between building brick and pavers. Sewer brick should be uniform in size and of regular, true shape so as to prevent their being laid with thin joints to form smooth, true surfaces. Great care is necessary in the construction of sewers with this material to make the joints water tight and it is because of this difficulty that concrete is becoming a favorite over brick construction.

Concrete, of late years, has been frequently employed in preference to brick or other kinds of masonry. It has the following advantages:

The cost is usually less than the cost of brick masonry.

The concrete exactly fits the irregularities of the excavation and hence gives better foundations.

There are no joints as in brick work to be made water tight though on the other hand it is not easy to make the body of the concrete entirely impervious to seepage.

Concrete can be readily moulded into any desired shape of sewer.

Concrete can be made by comparatively unskilled workmen if a skilled foreman is employed.

The concrete pipe, similar to that shown on Figure 2, Plate IX is rapidly coming into favor, especially that of the reinforced type. This pipe is made in sections usually three to four feet in length and of the diameter required, and reinforced with longitudinal and transverse bars. It is claimed that this method of making concrete sewers is superior to that of the monolithic type

because there is a better opportunity afforded for thorough inspection of each unit before it is laid in the sewer. Also it is possible to make the concrete considerably denser by the use of water tight moulds. It is further claimed as an advantage for this type of construction that the shrinkage which takes place while the concrete is settling is entirely accomplished before the pipe is laid in the line of the sewer. This avoids the cracks which are numerous in monolithic construction which is attributed to the above-mentioned cause.

Some authorities on sewer construction recommend paving the invert of concrete sewers with brick as it is claimed that brick is less subject to erosion than plain concrete. In the light of evidence furnished by city engineers from a large number of the cities of the United States, this conclusion cannot be based upon observation of well-made concrete sewers. It appears from such data that concrete, when the ingredients are properly proportioned, is properly mixed and handled, and carefully cured, has proven equal to and in some cases superior to the more expensive brick construction.

The writer therefore has no hesitancy in recommending the use of concrete wherever its use is economical from the standpoint of first cost provided the materials obtainable are first-class and provided further that the soil or sewage does not give strong alkali or acid reactions.

plate IX shows four ordinary types of concrete sewer. Figure 1 illustrates a type used in soft, wet ground. Figure 2 illustrates a type of reinforced concrete pipe sewer. Figure 3 the U-shaped concrete sewer, and Figure 4 a common type of reinforced monolithic sewer for good soil conditions.

APPURTENANCES.

Street inlets and catch basins are the means of admitting water from the street surfaces into the sewer. The storm inlet implies merely a branch sewer with a grated opening on the curb, while the catch basin has in addition a silt well or basin to catch sand, silt and other detritus preventing their entering the sewer. In combined sewers both inlets and catch basins should be trapped.

For storm sewers generally the catch basin is an economic failure and more or less of an offense to modern sanitary ideas. Theoretically they are supposed to eliminate all foreign substances and keep them from entering the main sewers, and if they can be cleaned after each storm they are not objectionable. The fact remains, however, that they do not eliminate all the sand, silt and other detritus because they are not cleaned after each storm. The attention of city officials generally is called to so many things which are above the surface that need doing that they find very little time to attend to such things as catch basins. If, however, they were attended to religiously the cost of so doing would be too great to justify their possible advantage over the direct inlet. There are two conditions under which the installation of the catch basin for storm sewers are justifiable, namely, when the velocities in the main sewers or in portions thereof below the inlet or catch basin are very low or extremely high, which conditions would allow, in the first instance, deposits to form in the sewers and when the velocities are extremely high the presence of sand and other detritus of a grity nature has a tendency to erode the pipes. The engineer, in designing the storm sewer systems should take into consideration the character of the detritus which is apt to be washed into the sewers and if it is of such nature as is not apt to form deposits or erode the pipes of the sewers then the catch basin should not be installed.

There are many types of gratings to be used in connection with inlets and catch basins now in the market. In selecting a type the following requirements should be fulfilled. The grating should be such as to eliminate debris such as large sticks and boards. They should be so arranged as to offer no obstruction to traffic and the opening should be large enough to accommodate all water that will arrive at that point during storms. The combination of the horizontal bars placed in the gutters at right angles to the curb with the horizontal bars across the opening in the curb itself makes a very efficient arrangement for grating. Simple types of inlet and catch basin are illustrated on Plate X, figures 5 and 6.

Manholes should be placed at intervals along the line of the storm sewer, particularly at points where grade changes and also where the alignment changes. These manholes offer the opportunity of inspection and when placed at the street intersections permit the best arrangement for connections to catch basins and street inlets. A few types of manholes are shown on Plate X, Figures 1 to 4 inclusive. Manholes must be built large anough at the bottom and for a couple of feet above the top of the sewer to permit a man to work comfortably. Four feet in diameter is a satisfactory size. Sometimes manholes are eliptical at the bottom with the long axis lengthwise of the sewer. This form is a little more expensive because of being more difficult to build. Above the top of the sewer the manhole should be gradually drawn to a diameter of about two feet. The cover castings may be of any manufacturers design satisfactory to the engineer,weighing at least three hundred and seventy-five pounds. For sanitary sewer manhole the covers are usually perforated with one-inch holes to permit ventilation and below it there is hung a heavy castiron dust pan to catch any dirt entering through the perforations. For strictly storm sewer construction,however,the perforations in the cover and the dust pans may be omitted. Manholes are usually built of brick,in fact brick is the most economical material to use in the construction of same. Some conditions,however,where special designs are called for require that concrete be used. In working out the detailed drawings for manholes,catch basins and other appurtenances to the storm sewer it is well to make the plans as explicit and perfect as is possible to make them because it is found easier to exact perfect work of the builders under perfect plans,than with rough,imperfect ones.

Manholes should be placed along the sewers at intervals of not over four hundred feet and at all points where there are abrupt changes in alignment or grade. Very large sewers do not require manholes at such frequent intervals as smaller sizes.

PLATE V.

RUN-OFF DIAGRAM

PLATE I.

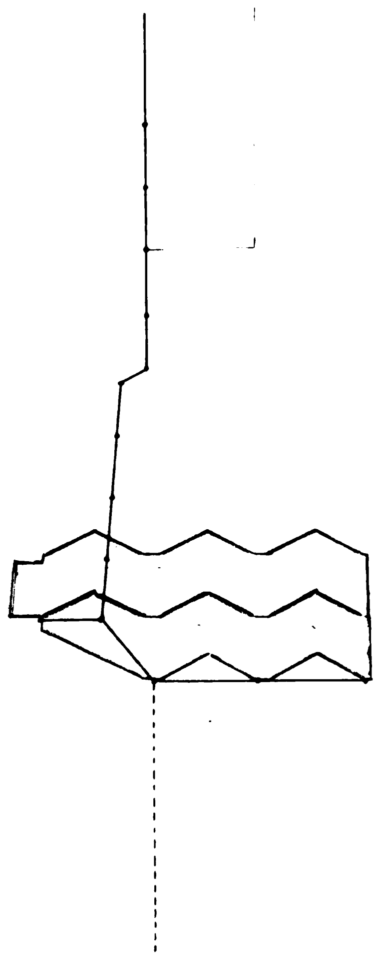

PLATE VII.

PLATE VIII.

PLATE IV.

PLATE V.

RUN-OFF DIAGRAM

PLATE IX.

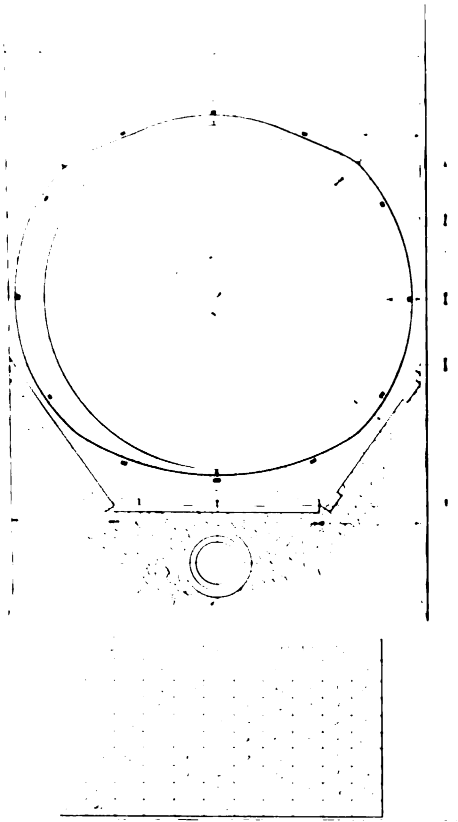

Fig. 1

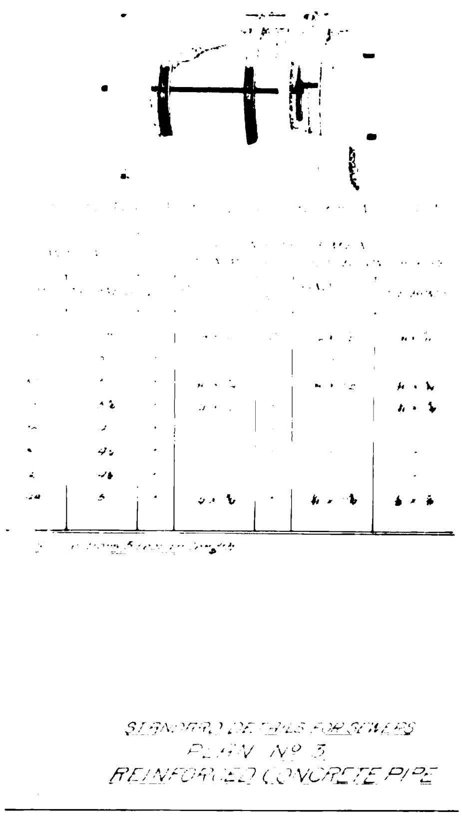

Fig. 2.

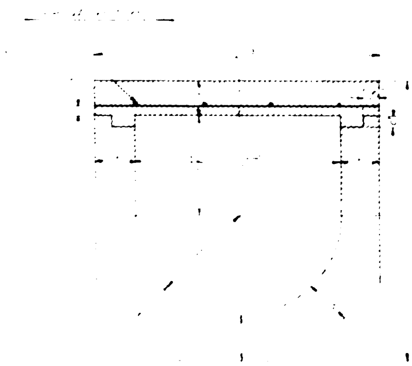

Fig. 3.

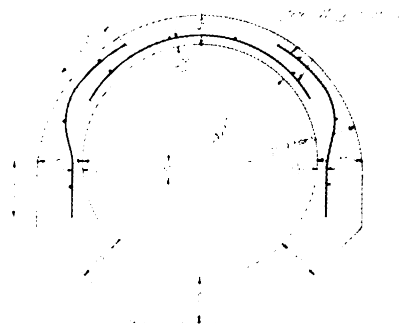

Fig. 4.

PLATE X.

Fig. 1.

Fig. 2.

Fig. 3.

INLET

Fig. 4.

Fig. 5.

Fig. 6.