RUNOFF COMPUTATIONS AND DRAINAGE INLETS FOR PARKWAYS IN LOS ANGELES

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SYNOPSIS

This paper deals primarily with computation of runoff under restricted conditions; that is, runoff from the flat paved surfaces and from the slopes of the grading section of a high speed express highway and its ingress and egress ramps. The method is based on hydrologic studies made locally and by engineers of other sections of the country.

As the charts and instructions are based on local rainfall curves and conditions, methods are suggested for their use with rainfall curves and conditions obtaining elsewhere.

Derivation is explained for charts of capacity of single and multiple grating catch basins. These charts can be used elsewhere without alteration for catch basins of the same construction and design.

HYDRAULIC ELEMENTS OF THE PARKWAY PAVING SECTION

Cross Section. A diagram of the parkway paving section is shown in Figure 1. The roadway is constructed as a plane surface sloping toward the gutter (Sx) with a rate of 0.01 ft. per foot on tangents (Fig. 2) and with higher rates for superelevation on curves (Fig. 3). For the flatter cross slopes, the water carrying capacity of the gutter is much inferior to that of a standard crowned roadway in that the water flows as a shallow stream of excessive width. Since high speed traffic tends to avoid even a thin sheet of water, it is necessary to limit the occurrence of streams wider than the width of a single traffic lane to a limited frequency; an average occurrence of once in a year is used locally.

An improved modification of the gutter formed by the plane surface of the roadway and the slightly batter-faced standard curb is the rolled gutter introduced to allow a disabled car to roll from the roadway to a parking space on a paved berm (Fig. 4). The water carrying capacity of this gutter is greater and the concentration of the greater percentage of the volume of flow over the gutter reduces the number and width of grating catch basins required to entrap the storm water.

Time of Concentration for Sheet Flow. In computing runoff, the time of concentration, which is a measure of the intercept on the mass rainfall curve of that portion of the intense rainfall most effective in producing the peak of the runoff, is computed as the time of flow over the paving surface from the roadway crown to the gutter (sheet flow) and the time of flow in the gutter to the point of entrapment in a catch basin (channel flow).

The writer has made an experimental investigation of sheet flow on tar and sand surface, tar and gravel surface, and clipped sod surface (1).[1] Because the planted slope of the cut of the parkway section is usually 2 to 1 or steeper, and the concentration of storm water therefrom is speedy, the paved surface is assumed to govern the time of concentration and to have a roughness comparable to the experimental tar and gravel surface.

The equation for the average depth of water (D_a, in inches) stored on the paving surface for varying values of length of flow (L, in feet), slope of flow (s, in feet per hundred feet), and rate of runoff (q, in inches per hour) is

$$D_a = \frac{0.0257 L^{0.384} q^{0.351}}{s^{0.367}} \qquad \text{Eq. 1}$$

The time of concentration (t_c, in minutes) for sheet flow is computed by the equation

$$t_c = \frac{60 D_a}{q} \qquad \text{Eq. 2}$$

which represents the horizontal (time) distance between the mass curves of rainfall supply and runoff. Substituting Eq. 1 in Eq. 2,

$$t_c = \frac{1.542 L^{0.384}}{s^{0.367} q^{0.649}} \qquad \text{Eq. 2a}$$

Referring to the diagram in Figure 1, in

[1] Numbers in parentheses refer to the list of references of the end of the paper.

which W is the width in feet of the plane surface pavement sloping toward the curb, and cross slope (Sx) and gutter slope (Sg) are expressed in feet per foot, the following equa-

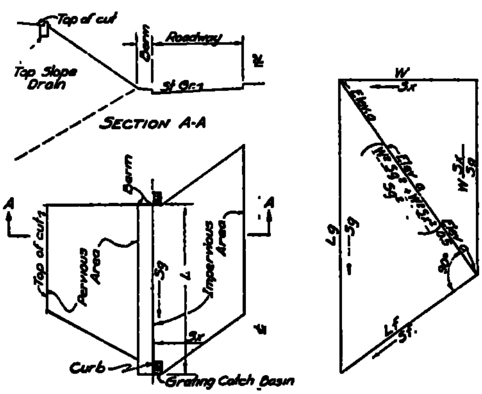

Figure 1

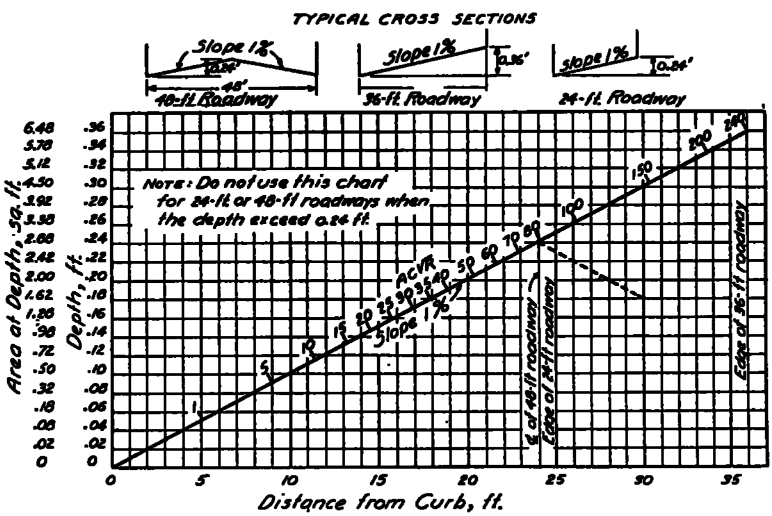

Figure 2. Hydraulic Elements for 24- and 36-ft. Roadway and one-half of 48-ft. Roadway. No superelevation, n = 0.012

tions for length of flow (L_f, in feet) and slope of flow (S_f, in feet per foot) are derived

$$L_f = \frac{(Sg^2 + Sx^2)^{0.5} W}{Sx} \qquad \text{Eq. 3}$$

and

$$S_f = (Sg^2 + Sx^2)^{0.5} \qquad \text{Eq. 4}$$

Substituting values of L_f and S_f from Eqs. 3 and 4 in Eq. 2a,

$$t_c = \frac{1.542\left(\dfrac{(Sg^2 + Sx^2)^{0.5} W}{Sx}\right)^{0.384}}{(100(Sg^2 + Sx^2)^{0.5})^{0.367} q^{0.649}}$$

$$= \frac{0.284(Sg^2 + Sx^2)^{0.0085}}{q^{0.649}} \frac{W^{0.384}}{Sx^{0.384}}$$

Since the term $(Sg^2 + Sx^2)^{0.0085}$ is relatively constant at 0.95±, the equation may be written

$$t_c = \frac{0.27(W/Sx)^{0.384}}{q^{0.649}} \qquad \text{Eq. 5}$$

Gutter Flow. Using the charts of $AC\sqrt{R}$ in Figures 2 and 3, applicable to gutters with standard batter-faced curb, working charts of velocities in feet per minute were drawn on log–log paper. These can be reduced to the following equation:

$$V = 1790\ Sg^{0.375}\ Sx^{0.275}\ Q^{0.275} \qquad \text{Eq. 6}$$

in which Sg and Sx are expressed in feet per foot and Q in cubic feet per second. (Note: For correctness in mathematics, the values of slope in Eqs. 1 to 6 are expressed either in feet per foot or in feet per hundred feet. Here-

after, for convenience, slope in percentage is used).

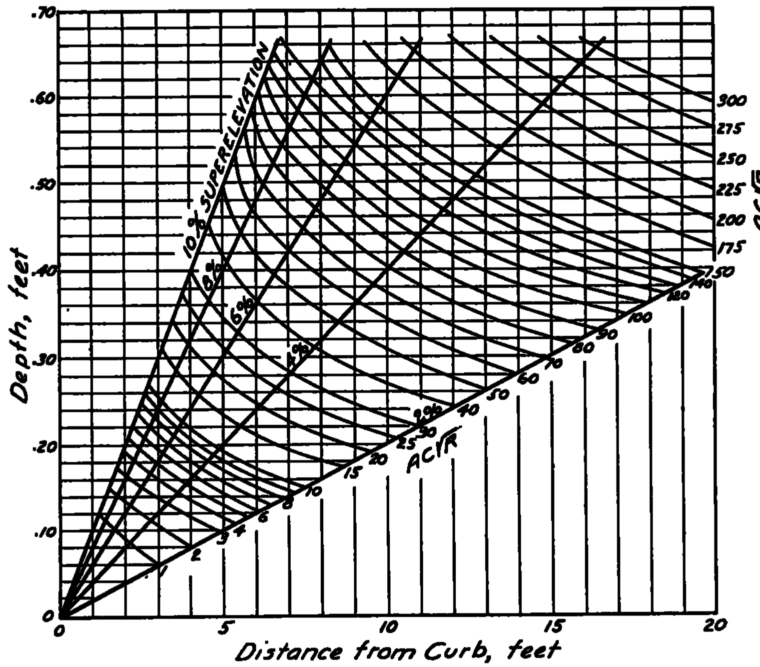

Figure 3. Hydraulic Elements of Roadway—Plane Cross-Section—Superelevated— $n = 0.012$

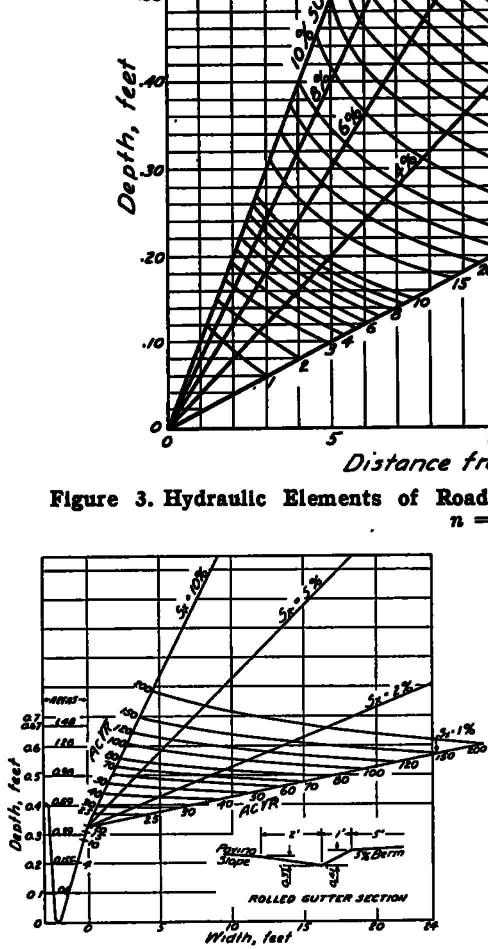

Figure 4. Hydraulic Elements, Rolled Gutter Section

For the rolled gutter, the velocity is approximately 112 per cent of that for the standard gutter with a 10 per cent cross slope.

RUNOFF COMPUTATION

Basis. The basis of the runoff computation is the paper, Surface Runoff Determination from Rainfall Without Using Coefficients, by W. W. Horner and S. W. Jens (2), and discussion thereof by the writer (1), the paper, a Method of Computing Urban Runoff, by the writer (3); and discussions thereoff by C. S. Jarvis, S. W. Jens, W. W. Horner (4), and the writer (5).

Analysis of Specific Problem. Runoff within the limits of the parkway consists of runoff from the paved plane surface and sometimes from the planted plane surface of a cut. For simplicity in computation, the pervious area of the cut surface is converted to an equivalent area of impervious surface. The curves in Figure 5 represent local rainfall curves for hourly intensities (R_H) of 0.5, 1.0, 1.5, and 2.0 in. per hour and the corresponding intensities of runoff (q) in inches per hour (second feet per acre) from impervious drainage areas.

Computation of Charts. Using (a) the runoff curves of Figure 5, (b) time charts for sheet flow based on Eq. 5, and (c) time charts for gutter flow based on Eq. 6, tabulations were made with fixed values of hourly rainfall curve, and width, cross slope, and gutter slope of pavement for progressively varying values of time of concentration (t_c), length of

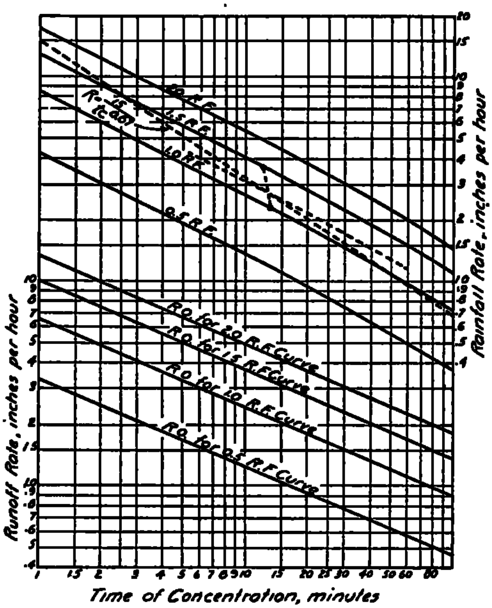

Figure 5

gutter (Lg), and quantity of runoff (Q, in cfs). A sample computation for preparation of the charts is contained in Table 1. Results of these tabulations are plotted in Figures 6 and 7.

TABLE 1

W = 48 FT.; Sx = 10 PER CENT; Sg = 5 PER CENT; R_H = 0.5 IN. PER HR.

Sta.	Area (Ac.)	Σ Area (Ac.)	q (cfs/A)	Q (cfs)	V (fpm)	Av. V	t_c (min.)
0 + 20	0.022	0.022	2.80	0.062	140		1.5
2 + 15		0.236	2.25	0.532	251	195	2.5
4 + 92		0.541	1.93	1.042	303	277	3.5
8 + 12		0.893	1.73	1.545	337	320	4.5
11 + 62		1.280	1.59	2.032	363	350	5.5
15 + 37		1.690	1.48	2.500	387	375	6.5
19 + 31		2.125	1.39	2.954	401	394	7.5
23 + 41		2.576	1.32	3.400	419	410	8.5
27 + 66		3.040	1.25	3.800	431	425	9.5

As the charts are based on three values of W, one value of Sx (5 per cent), five values of Sg, and four values of R_H, interpolation and extrapolation for other values are as follows:

For R_H, use straight line interpolation.

For W, use straight line interpolation between 24 ft., 36 ft., and 48 ft., and extrapolate above 48 ft. by the factor $\frac{1.05\ W.}{48}$

For Sx, multiply the chart Q by the factors in Table 2.

For rolled gutter, multiply chart Q by 1.10.

Sample Computation of Runoff to Inlet

Given: Lg = 900 ft.; Impervious area = 36,000 sq. ft.; Pervious area = 20,000 sq. ft.; assumed ratio of pervious to impervi-

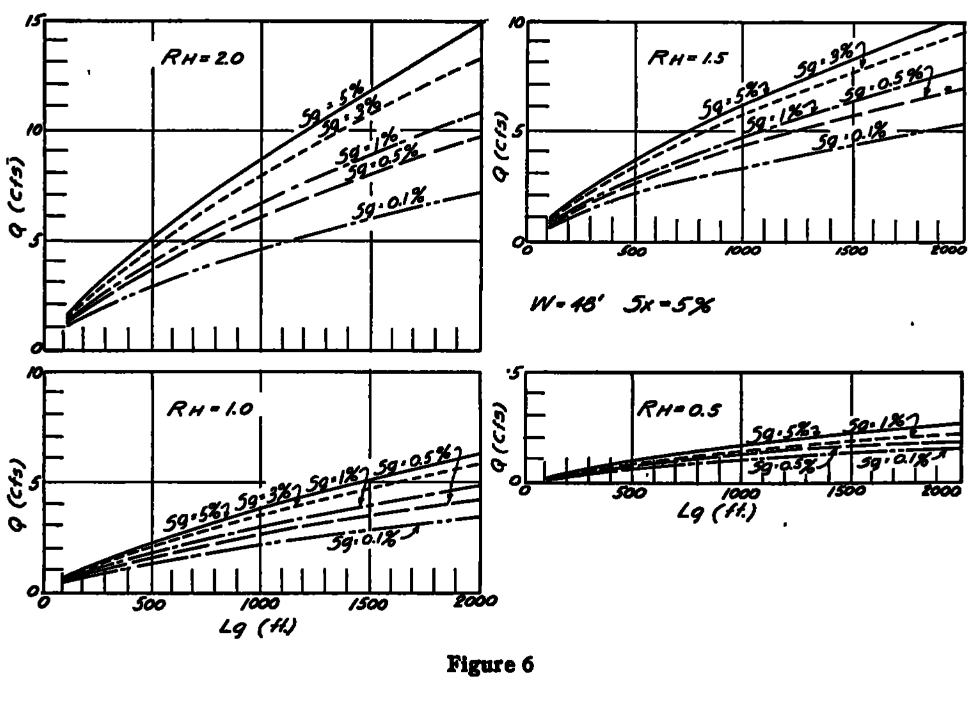

Figure 6

ous runoff = 0.815. Sx = 10 per cent; Sg = 2 per cent; R_H = 1.33.

Required: Q.

Solution:

Net Area = 36,000 + (0.815 × 20,000) = 52,300 sq. ft.

$$W = \frac{A}{Lg} = 52{,}300/900 = 58 \text{ ft.}$$

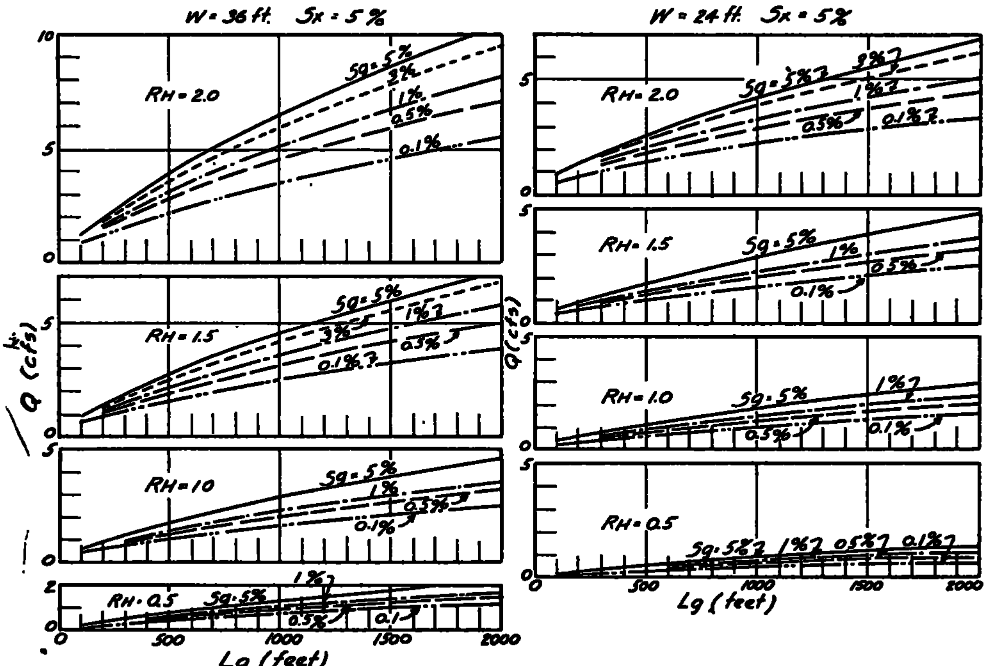

Figure 7

TABLE 2

Sx	= 1%	2%	3%	4%	5%	6%	8%	10%
Factor	= 0.78	0.88	0.93	0.97	1.00	1.02	1.06	1.10

From Chart 6, Q = 3.0 cfs for R_H = 1.0; W = 48 ft.

Q = 5.1 cfs for R_H = 1.5; W = 48 ft.

$$Q \text{ corrected to } R_H \text{ of } 1.33 = \frac{1.33 - 1.00}{1.50 - 1.00} (2.1 \text{ cfs}) + 3 \text{ cfs} = 4.4 \text{ cfs}$$

$$Q \text{ corrected to } W \text{ of } 58 = 1.05 \times \frac{58}{48} \times 4.4 \text{ cfs} = 5.6 \text{ cfs}$$

Q corrected to Sx of 10 per cent = 1.10 × 5.6 cfs = 6.2 cfs (Table 2).

Adaptation for Use Other Than Locally. Inspection of the rainfall curves in Figure 5 shows that they are of the approximate pattern of intensity,

$$R = K/t_c^{0.54}.$$

Available data from other localities show a wide range of curve patterns including many whose intensity for 1 hr. does not have the same relation to the intensities for the shorter times of concentration as these curves. The short times of concentration prevail for most parkway problems. To prepare runoff charts similar to Figures 6 and 7 for the rainfall curve or curves for any specific locality, proceed as follows:

1. Delineate the specific rainfall curve (say $R = 15/t_c^{0.67}$) on Fig. 5 as a broken line.
2. Select Lg's of 200, 500, 1000, and 2000 as necessary to delineate the runoff curve.
3. Use the same basic value of Sx (5 per cent) as used in Figures 6 and 7.
4. Use the same values of width (24, 36, and 48) and of Sg (0.1, 0.5, 1, 3, and 5 per cent).
5. Determine by inspection between which local (Los Angeles) rainfall curves

the probable t_c on the specific rainfall curve ($R = 15/t_c^{0.67}$) lies.

6. For these two curves, determine the values of Q for $Sx = 5$ per cent and for the specific values of Lg and Sg.

7. For these values of Q (in cfs), determine the corresponding values of q (in cfs per acre).

8. For these values of q, determine the values of t_c from the runoff curves in Figure 5.

9. Spot these values of t_c on the corresponding local rainfall curves in Figure 5, and connect the two points to form an intersection with the specific rainfall curve ($R = 15/t_c^{0.67}$).

10. Through this point of intersection, draw a curve parallel to the local rainfall curves down to $t_c = 60$ min., which point defines the value of R_H for the specific problem.

11. By interpolation, determine the value of Q for this R_H. This value of Q plotted as an ordinate on an abscissa of the Lg used in the problem forms a point on the new runoff curve.

Construction of Runoff Curves. A sample computation for a point on the runoff curves for the rainfall curve, $R = 15/t_c^{0.67}$, follows:

Lg = 2,000	Sg = 1%	Sx = 5%	W = 48 A = 2.2
R_H =	1.0	1.5	(Fig. 5)
Q =	4.80	7.90	(Fig. 6)
q =	2.18	3.60	(Q/2.2 ac.)
t_c =	12.8	10.3	(Fig. 5)
R_H =	1.18	(A curve parallel to rainfall curve of which the hourly rate, R_H = 1.0 and passing through the intersection of the rainfall curve, $R = 15/t_c^{0.67}$ and a line joining t_c = 12.8 on rainfall curve R_H = 1.0 to t_c = 10.3 on rainfall curve R_H = 1.5: see Fig. 5 for delineation).	

$$Q_{1.18} = 4.80 + \frac{1.18 - 1}{1.50 - 1}(7.9 - 4.8) = 5.92$$

This computation is repeated for the other values of Lg (1,000, 500, and 200). Runoff curves thus derived for $W = 48$ and $W = 36$ are delineated in Figure 8. In this figure, curves of the computed R_H are delineated for use with the chart of pervious area conversion factors (See Fig. 9), which is discussed as follows:

Pervious Area Treatment. If there is pervious area in the drainage tract, there is a further problem of transforming that area into an equivalent impervious area. The runoff from the face of the cut in a depressed section of the parkway may be small if the soil is sand or if the antecedent precipitation is negligible; however, if the cut is made into impervious subsurface soil or rock or if the antecedent precipitation is large, the resulting runoff may

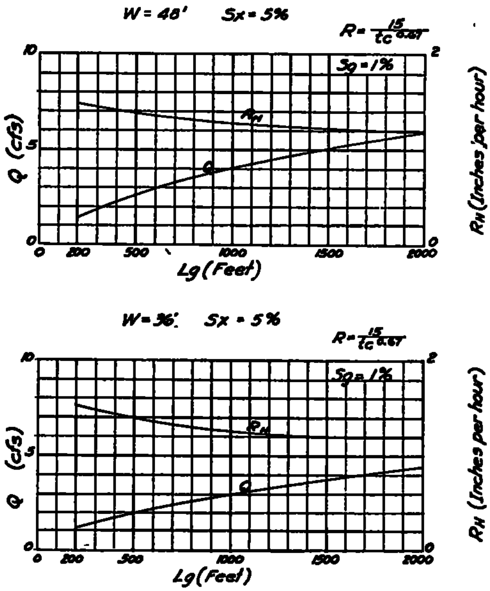

Figure 8

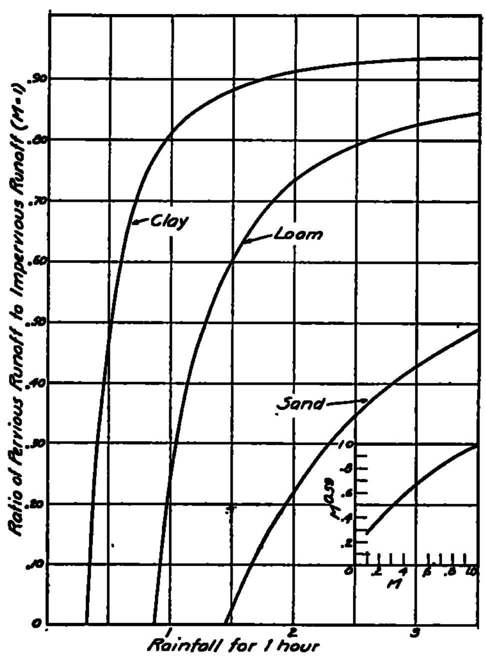

Figure 9

approach the intensity of that from impervious area. It is apparent that the factor to be applied to pervious areas to convert them to equivalent impervious areas must rest largely with the engineer and his appraisal of the character of the surface to be exposed in the cut. As a guide to judgment, the writer has investigated the effect of antecedent precipitation and other factors on runoff from pervious areas. From a statistical study of local rainfall records, a moisture factor "M" was derived (6) which was based on precipitation (including irrigation) occurring within 60 days previous to the high intensity storm of duration identical with t_c minutes, which precipitation was weighted by percentages decreasing as the time distance from the high storm increased and further weighted by an evaporation factor E (7). This composite factor M was analyzed in relation to pervious area runoff from gaged areas. It was concluded (8) that pervious runoff varies as $M^{0.59}$. Figure 9 shows values of conversion factors of pervious runoff (three soil types) to impervious runoff for various hourly rates of rainfall and for an M of 1. For values of M between the approximate limits of 0.20 and 1.00 (which is the range of local data), the factor values on Figure 9 can be adjusted to other values of M by applying the appropriate value of $M^{0.59}$ in direct ratio.

Sample Computation. The terrain of metropolitan Los Angeles is partly mountainous, and a wide range of rainfall curves must be used (See Fig. 2 in the paper by the writer, "A Method of Computing Urban Runoff" (3).) For this reason, interpolating between rainfall curves is necessary. In localities having a flat terrain, specific runoff curves such as those in Figure 8 can be drawn, and one step of interpolation can be avoided. Solution of a typical problem follows:

Given: Lg = 1000 ft.; Impervious area = 36,000 sq. ft.; Pervious area = 20,000 sq. ft.; Loam soil; $M = 0.25$; $R = 15/t_c^{0.67}$; Sg = 1 per cent; Sx = 1 per cent.

Required: Q.

Solution:

$R_H = 1.25$ (Fig. 8).

Factor for loam (for $R_H = 1.25$ and $M = 1$) = 0.484 (Fig. 9).

Net area = 36,000 + ($M^{0.59}$ × 0.484 × 20,000) = 36,000 + (0.44 × 0.484 × 20,000) = 40,250 sq. ft.

$W = A/Lg = 40{,}250/1000 = 40.25$ ft.

$Q_{48} = 4.00$ (Fig. 8).

$Q_{36} = 3.00$ (Fig. 8).

$$Q_{40.25} = 3.00 + \frac{40.25 - 36}{48 - 36}(4.00 - 3.00) = 3.35.$$

Q (corrected for Sx = 1 per cent) = 0.78 × 3.35 = 2.62 cfs (Table 2).

CATCH BASIN CAPACITIES

The fact that high speed traffic does not admit of the use of local depressions (9) (10) in the paved roadway at catch basins, seriously impairs the efficiency of all types of inlets. Not only is it impossible to narrow the width of the gutter flow stream preparatory to entrapping it, but, in the case of locations at sags in grade, a depth at the catch basin greater than that in the normal gutter flow section cannot be used for creating additional head in front of side-opening catch basins, as to do so would spread the water to greater widths in the traffic area. The rolled gutter and any gutter section which does not have a nearly vertical curb face prohibit the use of side-opening basins.

The capacity of side-opening catch basins, in the rare instances where they can be used advantageously, is determined with the equation

$$L_{CB} = \frac{0.33Q}{(0.5(d_u + d_L))^{1.5}} \qquad \text{Eq. 7}$$

in which d_u and d_L are the depths of the water at the curb in feet above and below the catch basin, and L_{CB} is the length of the catch basin opening in feet. This equation is theoretical and without sufficient flow measurements to substantiate it.

The grating catch basin used locally consists of a grating with bars parallel to the curb set in a steel frame over a concrete catchment box. The net length of opening parallel to the curb is 3 ft.; the gross width of opening is 24 in. with fifteen ½-in. x 3½-in. steel bars, spaced 1 in. clear from each other, which makes the net width of opening 16½ in.

The capacity of the grating catch basins is based on the equation for freely falling bodies,

$$F = \tfrac{1}{2}gt^2 \qquad \text{Eq. 8}$$

The water in the gutter flowing above the grating tends to fall into the basin. Free fall is hindered in three ways:

1. Frictional resistance develops between the bars.
2. The bars reduce the gross width by one third so that a part of the water tends to skid along the top of the bar until it can fall to either side.
3. If the velocity of the segment of water over the grating (V_H in feet per second) is great enough, the upper layer will overshoot the basin and continue on down the gutter.

To account for the first two items, the length of the basin is assumed to be 1.5 ft.,

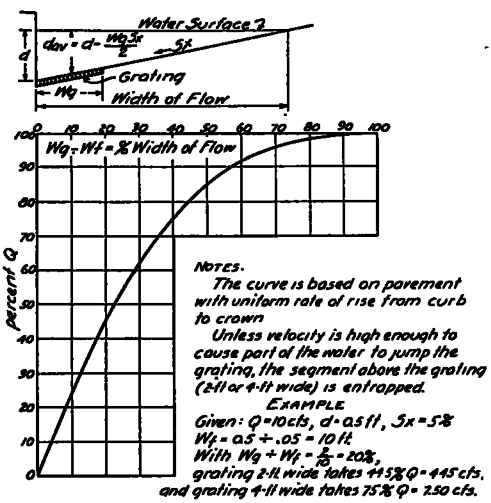

Figure 10. Grating Catch Basin Capacity, Grating in Plane of Pavement

which makes the time $\frac{1.5}{V_H}$ and transforms Eq. 8 into

$$F = \frac{36.18}{V_H^2} \qquad \text{Eq. 8a}$$

When the average depth of segment of water at the upper end of the grating is less than F, the whole segment is assumed to be entrapped; when the depth is greater, the fraction of the segment, $\frac{d_{av} - F}{d_{av}}$, is assumed to flow past. Figures 10, 11, and 12 show charts and examples for solution of the capacities of grating basins.

While the methods of computation for grating basin capacity are analytical, observation during rainstorms confirms them for the higher gutter velocities. For comparatively low velocities, where the water in the segment over the basin drops below the top of the grating bars before the lower end of the grating is reached, some additional water will side slip

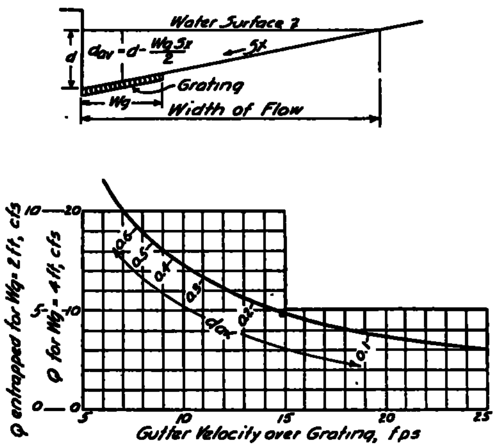

Figure 11. Grating Catch Basin Capacity. Effect of Gutter Velocity on Capacity. (Grating in plane of pavement.)

Gutter Velocity over the grating is $Q \div a$.

$$a = Wg\left(d - \frac{WgSx}{2}\right)$$

Q (over grating) can be found by use of the percentage chart, Figure 10. To determine the inflow to a grating, enter the chart above with d_{av}, and V. If V appears to the right of d_{av}, read Q from the curve; if to the left all Q indicated by the percentage chart enters the basin.

Example:—

Given: $Q = 20$ cfs; $d = 0.5'$; $Sx = 5\%$.

$W_f = 0.5 \div 0.05 = 10'$; $d_{av} = 0.5 - \frac{2 \times 0.05}{2} = 0.45$.

Q over 2-ft. grating = 44.5% of 20 cfs = 8.9 cfs.

$a = Wg\left(d - \frac{WgSx}{2}\right) = 2\left(0.5 - \frac{2 \times 0.05}{2}\right) = 0.9$ sq. ft.

$V = 8.9 \div 0.9 = 9.9$ fps.

Q (from above chart) = 7.2 cfs. as V is at right of d_{av} (0.45).

into the basin. For basins in sags, where the gutter slope is necessarily low on account of the vertical curve, flow from the gutters on both sides will enter the basin in addition to some side slip flow.

Observation of the action of grating basins shows that they are vulnerable to partial

stoppage by debris. Grass clippings and other fine debris, carried either by the low velocity of flat grades or the first flush of water after a prolonged dry period, build a mat at the upper end of the grating which increases in size and usually stays in place until the rainstorm is over. In local designs for standard streets, it has been possible to avoid this condition by placing a side-opening upstream from the grating; in the case of parkways, the problem must be solved either by careful maintenance or by a combination of maintenance and the introduction of a factor of safety.

Figure 12. Capacity Curves for Grating Catch Basins. Rolled Gutter

ACKNOWLEDGEMENT

Design of Parkways within the City of Los Angeles is a joint cooperative function of the City and the Division of Highways of the State Department of Public Works, S. V. Cortelyou, District Engineer, District VII. Lloyd Aldrich is City Engineer and Merrill Butler, Deputy Engineer (Design). H. H. Winter and L. W. Armstrong, Principal Civil Engineers, are in charge, respectively, of the Street and Parkway Design Division and the Storm Drain Design Division of the City Bureau of Engineering.

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DISCUSSION

MR. C. N. CONNER, *Public Roads Administration:* The paper by Mr. Hicks is a valuable and timely contribution on the subject of surface drainage of highways and undoubtedly will be welcomed by engineers responsible for the design of drainage facilities for express highways in urban areas.

The problems to be solved in highway and street drainage and the general method of their solution are somewhat similar to those used in the design of airports. It is gratifying to observe the author has studied current thought on rate of run-off governing design. Apparently he has concluded that relations between rainfall and run-off are complex and that great refinement in computations is not necessary perhaps because of approximations made in design assumptions.

There appears to be no accurate method of predicting the peak rate of run-off from an airport or road surface and where run-off coefficients are to be used for any given set of conditions careful judgment in their determination is required. In this connection reference is made to the Highway Research Board's Proceedings of 1942 which contain an important paper on Run-off from Flight Strips by Carl F. Izzard which describes exper-

imental methods used and results obtained in an investigation of run-off from paved and turf surfaces. The project is a cooperative undertaking of the Public Roads Administration and the Soils Conservation Service to obtain data on the relationship of rainfall to run-off for use in designing drainage systems for flight strips.

A practical approach to the design of drainage for airports is covered in some detail with illustrative examples in Section III of "Principles of Highway Construction as Applied to Airports, Flight Strips and Other Landing Areas for Aircraft" published by the Public Roads Administration in June 1943. The section discusses amongst other items the design of surface and subsurface drainage systems, size and spacing of drains and inlets, types of pipes, grating and gutters, as well as various methods commonly used in estimating rainfall and run-off. As the title indicates the principles involved and methods used should be of interest to both highway and airport designers.

It is hoped that Mr. Hicks' paper will be followed by discussion and additional papers on this important subject and its application to express highways in rural as well as urban areas.

CONTROLLED REFLECTION. A PLAN FOR GREATER SAFETY IN NIGHT DRIVING

By Eugene C. Bingham
Lafayette College

SYNOPSIS

Could it be demonstrated that our highway death-toll is unnecessary, we might after the war regard the present situation as unbearable. Lack of visibility, glare and the smooth condition of the pavements are all remediable. It is proposed that the surface of the pavement be given a fluted surface, with small nearly-vertical reflectors which will reflect the light of the headlights back to the driver to give visibility and not forward to produce glare. The roughness will not cause noticeable roughness or noise but will allow water to flow around the high points and prevent skidding. Visual observation, photographs or, better still, quantitative measurement of the light reflected with different surfaces prove conclusively the very great advantages to be obtained. The efficacy of the reflectors will depend upon their character and the care and expense spent upon their installation. The reflectors may first be tried out for the center strip or dividing line, or for curbs at the side of the road, but they should in time cover the entire pavement so that the entire highway will be highly illuminated several hundred feet ahead, without other source of light than the driver's own head-lights. Special treatment is suggested for crossings, curves and road-signs which will be described in detail. Questions as to methods of construction, durability and cost are to be considered. It is shown that the problem is one which is capable of exact scientific treatment. Controlled reflection may be applied to various types of roads, concrete, brick, asphalt.

Road safety may not be a hopeless problem. According to legend the Minotaur of Crete exacted a tribute of seven youths and seven maidens from Athens periodically. The important thing is that the Minotaur is no more, whereas the sacrifice of some 40,000 American lives to the labyrinth of our highways is a continuing and very real menace. Measured both in the loss of life and limb and in property as well, this is the equivalent of a great war, but one which is never won but ever growing in intensity with the years without any respite