Appendix B - Spread-Discharge for Parabolic Sections

A parabolic cross-section can be described by the equation:

$$y = ax - bx^2 \quad \text{(B.1)}$$

where:

a	=	2H/B
b	=	H/B2
H	=	Crown height, ft (m)
B	=	Half width, ft (m)

Figure B.1 shows the relationships between a, b, crown height, H, and half width, B.

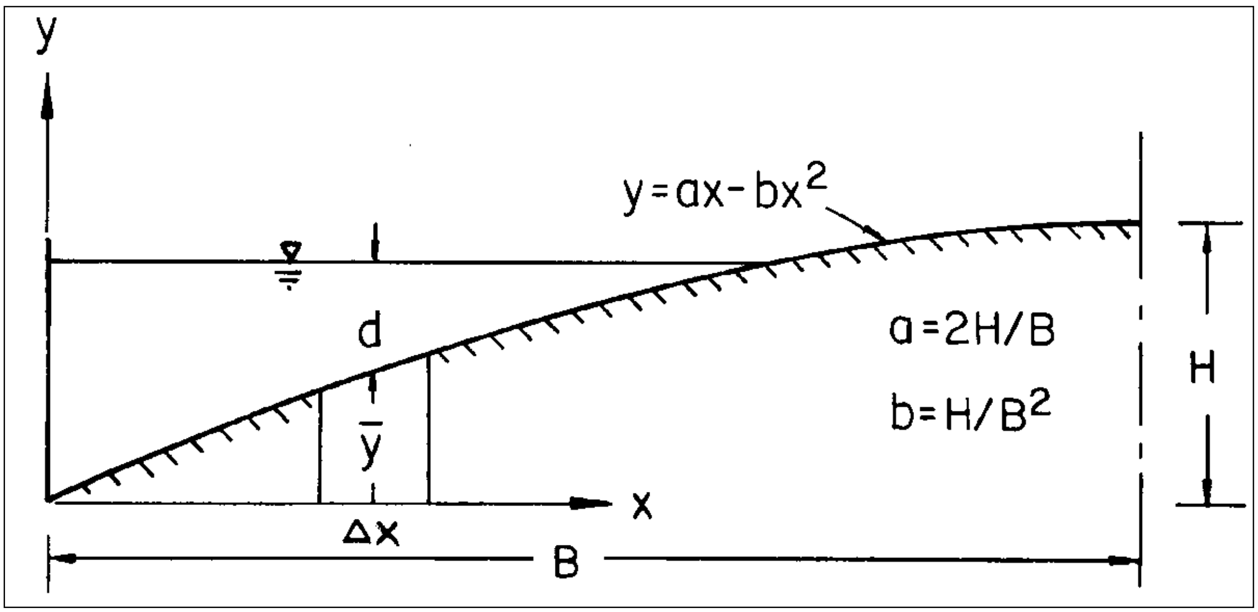

Figure B.1. Properties of a parabolic curve.

To determine total gutter flow, divide the cross-section into segments of equal width and compute the discharge for each segment by Manning's equation. The parabola can be approximated with 2 ft chords. The total discharge is the sum of the discharges in all segments.

The crown height, H, and half width, B, vary from one design to another. Since discharge is directly related to the configuration of the cross-section, discharge-depth (or spread) relationships developed for one configuration do not apply for roadways of other configurations, therefore, the designer develops relationships for each roadway configuration.

The following procedure illustrates the development of a conveyance curve for a parabolic pavement section with a half width, B = 23.9 ft and a crown height, H = 0.48 ft. The Manning's n = 0.016. Table B.1 summarizes the results of the procedure for spreads of 2, 4, and 6 ft.

Step 1. Choose the width of segment, Δx.

Choose the segment width for which the vertical rise will be computed. In this case, select 2 ft and record this in column 1 of Table B.1.

Step 2. Compute the vertical rise.

For H = 0.48 ft and B = 24 ft, equation B.1 becomes:

$y = 0.04x - 0.00083x^2$

Compute the vertical rise for each segment width and enter it into column 2.

Step 3. Compute the mean rise, y_a, of each segment.

Compute the mean rise of each segment and record in column 3.

Step 4. Compute the conveyance from the first segment width.

Depth of flow at the curb, d, for a given spread, T, is equal to the vertical rise, y, shown in column 2. The average flow depth for any segment is equal to depth at the curb for the spread minus the mean rise in that segment. For example, depth at curb for a 2 ft spread is equal to 0.0767 ft. The mean rise in the segment is equal to 0.0384 ft. Therefore, average flow depth in the segment, d = 0.0767 - 0.0384 = 0.0383 ft. Record in column 4.

Compute depth to the five-thirds power and record in column 5.

The sum of d to the five-thirds is 0.0043 as shown in the table.

$Q/S^{0.5} = K = (K_u\ (\Delta x)\ d^{5/3}) / n$

Where K is conveyance and depth, d, is used as an approximation for hydraulic radius, R. K_u is 1.49 for English units.

For this segment:

$K = [1.49\ (\Delta x)\ d^{5/3}] / n = (1.49\ (2)\ (0.0043))/0.016 = 0.8\ ft^3/s.$

Step 5. Compute the conveyance from the first and second segment widths.

Compute average depth of flow in the next 2-foot segment and enter it into column 6. Average flow depth in the first 2-foot segment nearest the curb is equal to the depth at the curb minus the average rise in the segment.

$d = y - y_a = 0.1467 - 0.0384 = 0.1083$ ft

Similarly, the average flow depth in the second 2-foot segment away from the curb is:

d = 0.1467 - 0.1117 = 0.0350 ft

The sum of d to the five-thirds is 0.0281 as shown in the table.

For the first two segments:

$K = [1.49\ (\Delta x)\ d^{5/3}] / n = (1.49\ (2)\ (0.0281))/0.016 = 5.23\ ft^3/s.$

Step 6. Repeat for all additional segment widths.

Columns 8 and 9 are computed in the same manner. For T = 6 ft, K = 14.27 ft^3/s.

Repeat the same analysis for spreads up to the half-section width. The computation is limited for to depths less than or equal to the curb height.

Table B.1. Conveyance computations, parabolic street section.

Distance From Curb	Vertical Rise y	Ave. Rise Y_a	T = 2 ft Ave. Flow Depth (d)	T = 2 ft $d^{5/3}$	T = 4 ft Ave. Flow Depth (d)	T = 4 ft $d^{5/3}$	T = 6 ft Ave. Flow Depth (d)	T = 6 ft $d^{5/3}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0	0	0.0384	0.0383	0.0043	0.1083	0.0244	0.1716	0.0527
2	0.0767	0.1117	-	-	0.0350	0.0037	0.0983	0.0208
4	0.1467	0.1784	-	-	-	-	0.0316	0.0031
6	0.2100	0.2384	-	-	-	-	-	-
8	0.2667	0.2917	-	-	-	-	-	-
10	0.3167	0.3384	-	-	-	-	-	-
12	0.3600	0.3784	-	-	-	-	-	-
14	0.3967	0.4118	-	-	-	-	-	-
16	0.4268	0.4385	-	-	-	-	-	-
18	0.4501	0.4585	-	-	-	-	-	-
20	0.4668	0.4718	-	-	-	-	-	-
22	0.4768	0.4784	-	-	-	-	-	-
24	0.4800	-	-	-	-	-	-	-
Sum	-	-	-	0.0043	-	0.0281	-	0.0766

Table B.2 summarizes the results of the analyses for spreads of 8 to 24 ft, which are also plotted in Figure B.2. For a given spread or flow depth at the curb, the conveyance can be read from the figure and the discharge computed from $Q = KS^{0.5}$. For a given discharge and longitudinal slope, the flow depth or spread can be read directly from the figure by first computing the conveyance, $K = Q/S^{0.5}$, and using this value to enter the figure.

As shown in the figure, for a conveyance of 30 ft^3/s (based on Q = 3 ft^3/s and S = 0.01 ft/ft) the water depth at the curve equals 0.275 ft. Using the spread curve at that depth yields a spread of 8.4 ft for the given parabolic curve parameters (H = 0.48 ft and B = 24 ft)

Table B.2. Conveyance and spread for a parabolic street section.

Quantity	T (ft) 8	10	12	14	16	18	20	22	24
d (ft)	0.267	0.317	0.360	0.397	0.427	0.450	0.467	0.477	0.480
K (ft^3/s)	27.53	44.71	64.45	85.26	105.54	123.63	137.98	147.26	150.5

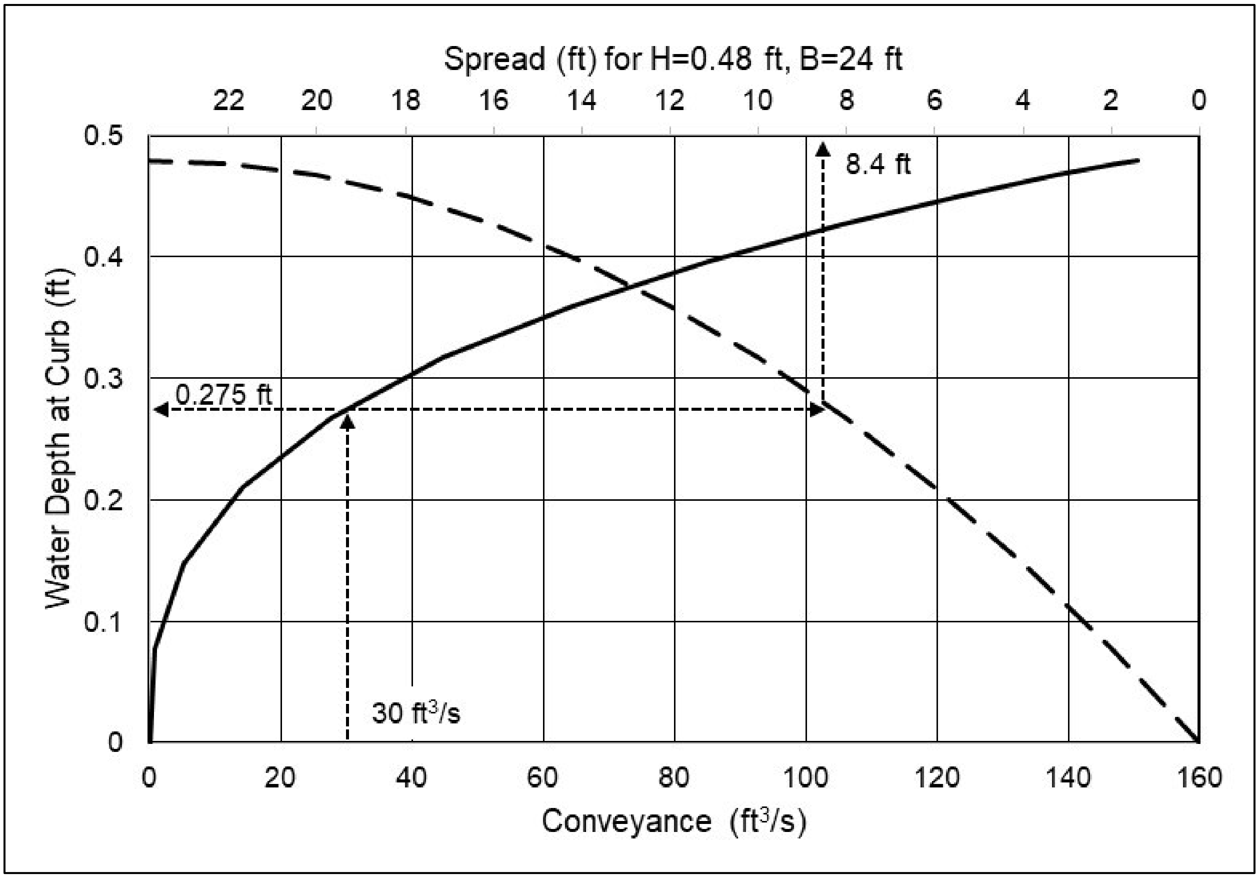

Figure B.2. Conveyance curve for a parabolic cross-section with example application.