Pavement Drainage

This section was extracted from the Urban Drainage Design Manual, **Hydraulic Engineering Circular Number 22 (HEC-22)**, Pavement Drainage; published by the Federal Highway Administration in November 1996. All charts referred to in this section are provided in HEC 22 Charts.

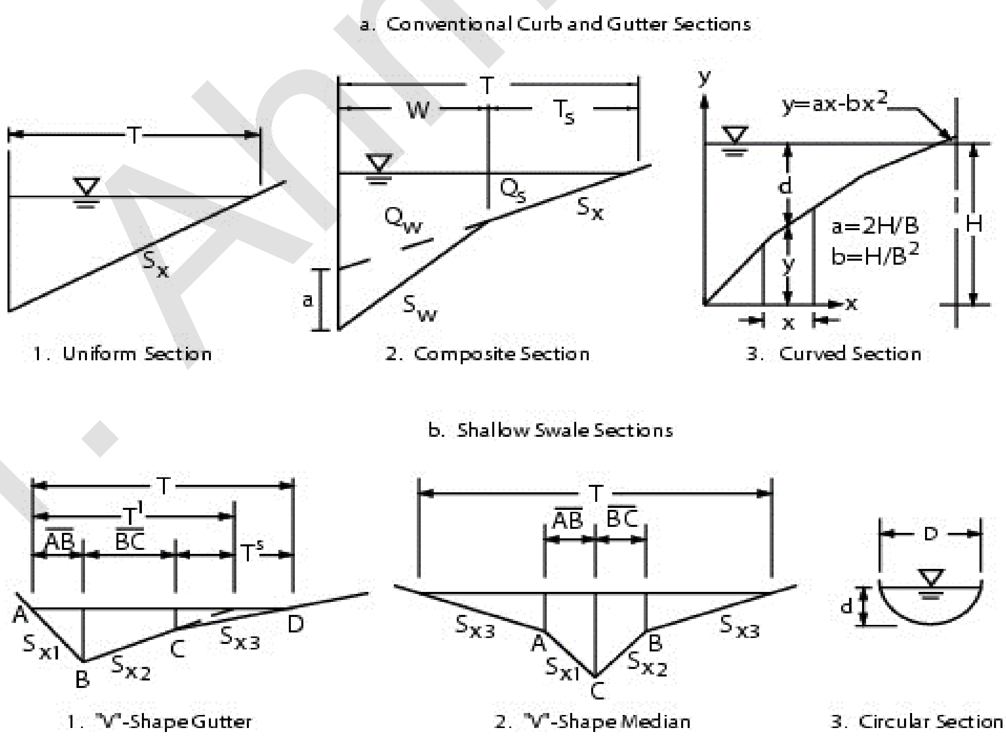
1.1 Selection of Check Storm and Spread

Table 6-1: Suggested Minimum Design Frequency and Spread

Road Classification		Design Frequency	Design Spread
High Volume, Divided, or Bi-Directional	<70 km/hr (45 mph)	10-year	Shoulder +1m
	>70 km/hr (45 mph)	10-year	Shoulder
	Sag Point	5-year	Shoulder +1m
Collector	<70 km/hr (45 mph)	10-year	1/2 driving lane
	>70 km/hr (45 mph)	10-year	Shoulder
	Sag Point	10-year	1/2 driving lane
Local Streets	Low ADT	5-year	1/2 driving lane
	High ADT	10-year	1/2 driving lane
	Sag Point	10-year	1/2 driving lane

Grate Inlets on Grade

1.2 Roadside and Median Channels



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1.3 Flow in Gutters

$$Q = \frac{k_c}{n} S_x^{1.67} S_L^{0.50} T^{2.67}$$

Where:

Kc	=	0.376
n	=	Manning's coefficient
Q	=	Flow rate (m^3/s)
T	=	Width of flow—spread (m)
S_X	=	Cross slope (m/m)
S_L	=	Longitudinal slope (m/m)

$$d = \mathrm{T}S_x$$

Where:

d	=	Depth of flow (m)
T	=	Width of flow—spread (m)
S_X	=	Cross slope (m/m)

Table 6-3: Manning's n for Street and Pavement Gutters

Type of Gutter or Pavement	Manning's n
Concrete gutter, trowled finish	0.012
Asphalt pavement, smooth texture	0.013
Asphalt pavement, rough texture	0.016
Concrete gutter-asphalt pavement, smooth	0.013
Concrete gutter-asphalt pavement, rough	0.015
Concrete pavement, float finish	0.014
Concrete pavement, broom finish	0.016
For gutters with small slope, where sediment may accumulate, increase the above values of "n" by 0.02	
Reference: USDOT, FHWA, HDS-3	

1.4 Gutter Flow Velocity

$$V = \frac{k_c}{n} S_x^{0.67} S_L^{0.50} T^{0.67}$$

Where:

V	=	Velocity in the triangular channel (m/sec.)
Kc	=	0.752
n	=	Manning's coefficient
S_X	=	Cross slope (m/m)
S_L	=	Longitudinal slope (m/m)
T	=	Width of flow—spread (m)

1.5 Grate Inlets

The ratio of frontal flow to total gutter flow, E_o, for a uniform cross slope

$$E_O = \frac{Q_W}{Q} = 1 - \left[1 - \frac{W}{T}\right]^{2.67}$$

Where:

Q	=	Total gutter flow (m^3/sec.)
Q_W	=	Flow in width, W (m^3/sec.)
W	=	Width of depressed gutter or grate (m)
T	=	Total spread of water (m)

The ratio of side flow, Q_s, to total gutter flow is:

$$E_s = \frac{Q_S}{Q} = 1 - \frac{Q_W}{Q} = 1 - E_O$$

The ratio of frontal flow intercepted to total frontal flow, R_f,

$$R_F = 1 - k_c(V - V_O)$$

Where:

Kc	=	0.295
V	=	Velocity of flow in gutter (m/sec.)
V_O	=	Gutter velocity where splash-over first occurs (m/sec.)
R_f	=	Frontal Flow Factor, cannot exceed 1.0.

Empirical Equations for Splash-Over Velocity Calculation
Splash-Over Velocity (ft/s)
$V_O = \alpha + \beta L - \gamma L^2 + \eta L^3$

Type of Grate	α	β	γ	η
Bar P-1-7/8	2.22	4.03	0.65	0.06
Bar P-1-1/8	1.76	3.12	0.45	0.03
Vane Grate	0.30	4.85	1.31	0.15
45° Bar	0.99	2.64	0.36	0.03
Bar P-1-7/8-4	0.74	2.44	0.27	0.02
30° Bar	0.51	2.34	0.20	0.01
Reticuline	0.28	2.28	0.18	0.01

The ratio of side flow intercepted to total side flow, R_s, or side flow interception efficiency,

$$R_S = \frac{1}{1 + \frac{k_c V^{1.8}}{Sx \cdot L^{2.3}}}$$

Where:

Kc = 0.0828

R_f = Side Flow Factor.

A deficiency in developing empirical equations and charts from experimental data is evident in Chart 6. The fact that a grate will intercept all or almost all of the side flow where the velocity is low and the spread only slightly exceeds the grate width is not reflected in the chart. Error due to this deficiency is very small. In fact, where velocities are high, **side flow interception may be neglected** without significant error.

The efficiency, E, of a grate is expressed as:

$$\mathrm{E} = R_F E_O + R_S(1\text{-}\mathrm{E_O})$$

The first term on the right side of the previous Equation is the **ratio of intercepted frontal flow to total gutter flow**, and the second term is the **ratio of intercepted side flow to total side flow**. The second term is insignificant with high velocities and short grates.

The interception capacity of a grate inlet on grade is equal to the efficiency of the grate multiplied by the total gutter flow:

$$Q_i = \mathrm{EQ} = Q\,[R_F E_O + R_S(1\text{-}\mathrm{E_O})]$$

Flow that is not intercepted by an inlet is termed carryover or bypass and is defined as:

$$Q_b = \mathrm{Q} - Q_i$$

Where:

Q_b = Bypass flow, m^3/s

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Grate Inlets in SAG

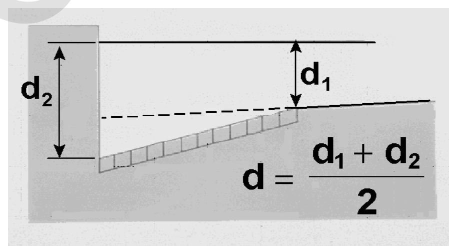
Inlets in sag locations operate as weirs under low head conditions and as orifices at greater depths. Orifice flow begins at depths dependent on the grate size, the curb opening height, or the slot width of the inlet. At depths between those at which weir flow definitely prevails and those at which orifice flow prevails, flowis in a transition stage. At these depths, control is ill-defined and flow may fluctuate between weir and orifice control. Design procedures presented here are based on a conservative approach to estimating the capacity of inlets in sump locations.

The efficiency of inlets in passing debris is critical in sag locations because all runoff which enters the sag must be passed through the inlet. Total or partial clogging of inlets in these locations can result in hazardous ponded conditions. Grate inlets alone are not recommended for use in sag locations because of the tendencies of grates to become clogged. Combination inlets or curb-opening inlets are recommended for use in these locations.

A grate inlet in a sag location operates as a weir to depths dependent on the bar configuration and size of the grate and as an orifice at greater depths. Grates of larger dimension will operate as weirs to greater depths than smaller grates or grates with less opening area.

2.1 The capacity of grate inlets operating as weirs is:

$$Q_{wi} = C_w \times P \times d^{1.50}$$



Where:

C_W = 1.660

P = Perimeter of the grate in (m) disregarding the side against the curb = 2 W + L

L = Length of the grate (m)

W = Width of the grate (m)

d = Flow depth at middle of grate(m) = 0.50 (d_1 + d_2)

2.2 The capacity of a grate inlet operating as an orifice is:

$$Q_{oi} = C_o \times A_g \times (2gd)^{0.5}$$

Where:

C_o = 0.670 Orifice coefficient

A_g = Clear opening of the grate (m^2)

g = Gravitational acceleration (9.81 m/sec^2)

P-50: Parallel bar grate with bar spacing 48 mm (1-7/8 in) on center (Figure 1-1).

P-50x100: Parallel bar grate with bar spacing 48 mm (1-7/8 in) on center and 10 mm (3/8 in) diameter lateral rods spaced at 102 mm (4 in) on center (Figure 1-1).

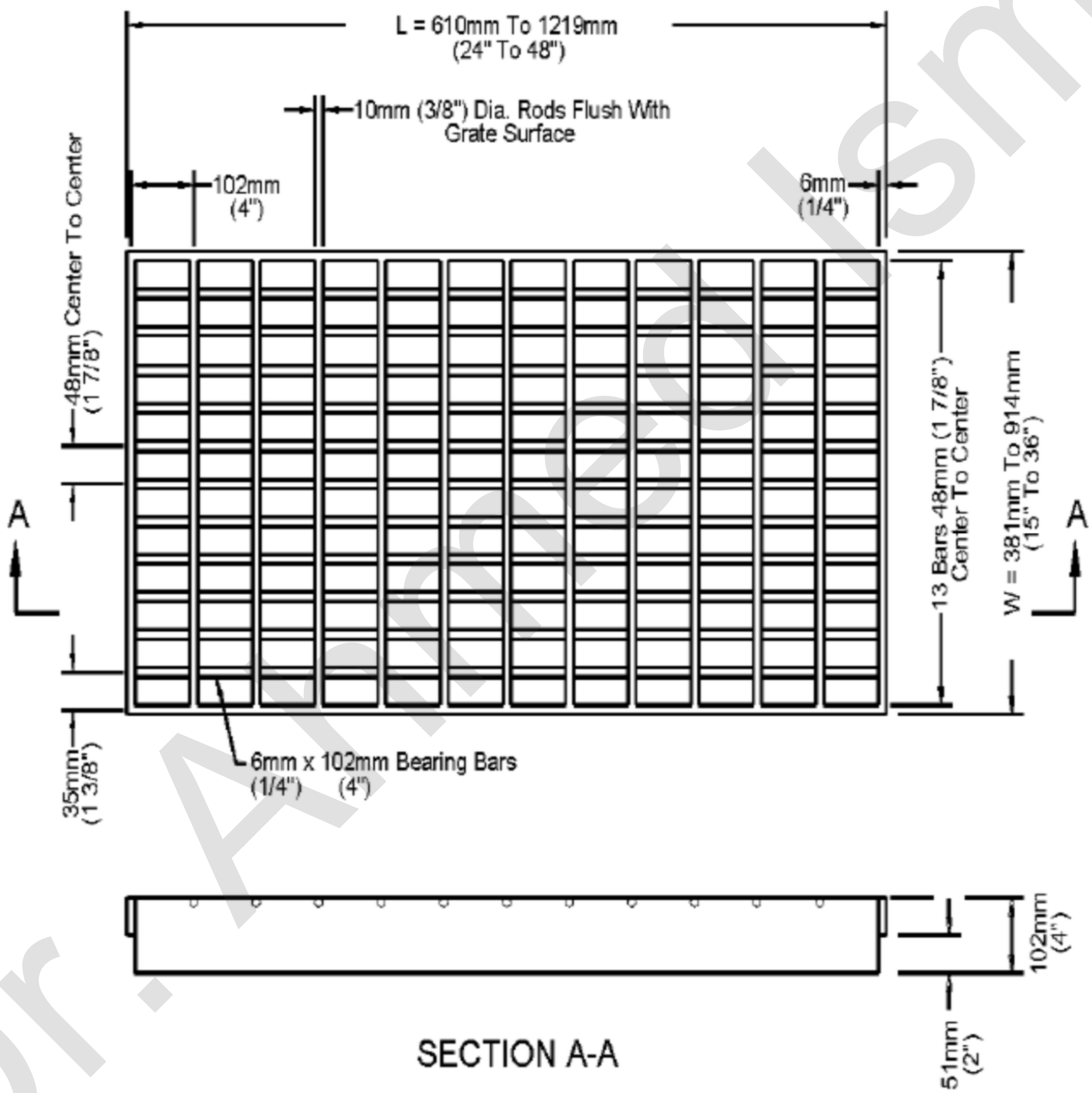


Figure 1-1: P-50 and P-50x100 Grates

P-30: Parallel bar grate with 29 mm (1-1/8 in) on center bar spacing (Figure 1-2).

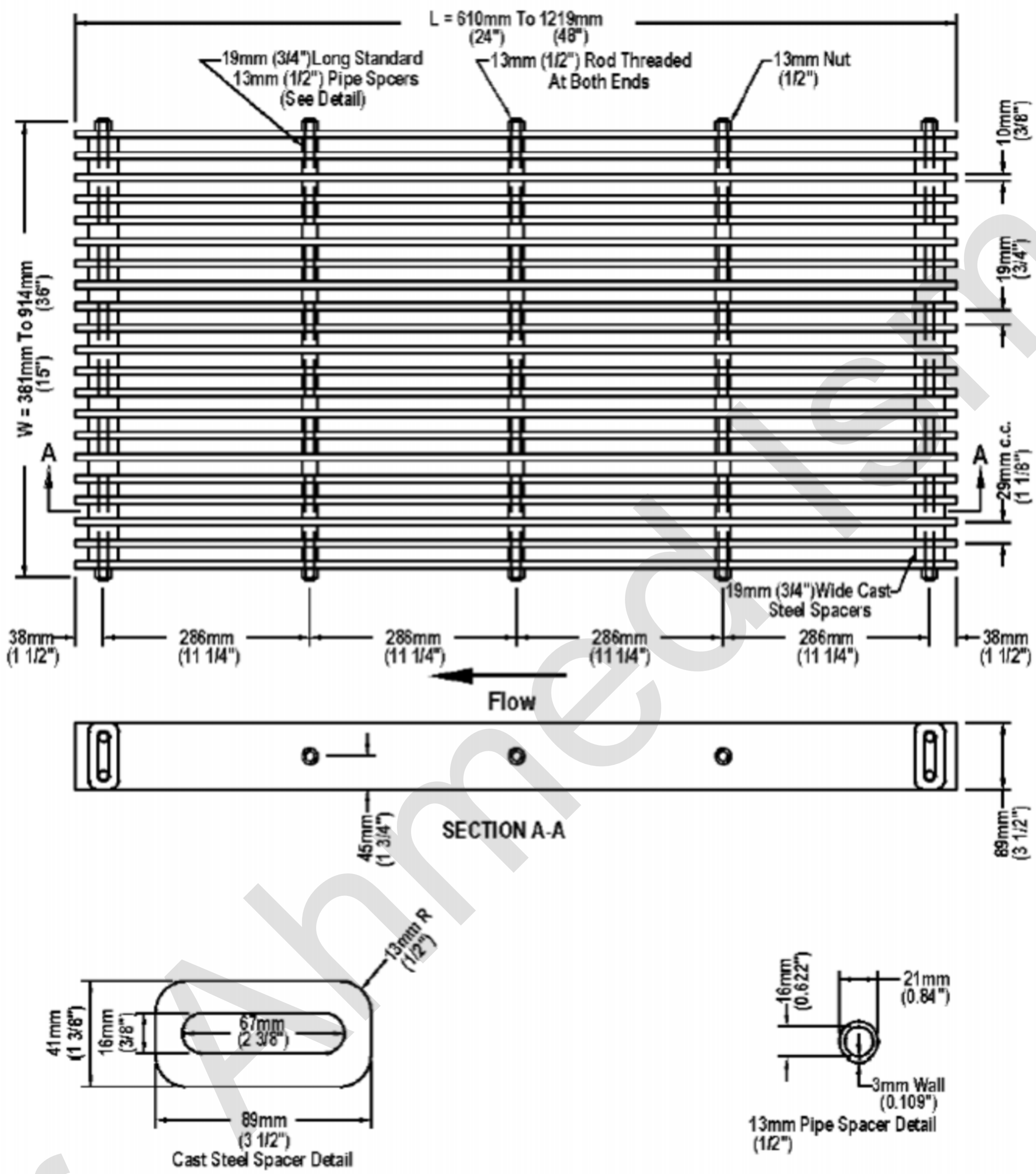


Figure 1-2: P-30 Grate

Curved Vane: Curved vane grate with 83 mm (3-1/4 in) longitudinal bar and 108 mm (4-1/4 in) transverse bar spacing on center Figure 1-3).

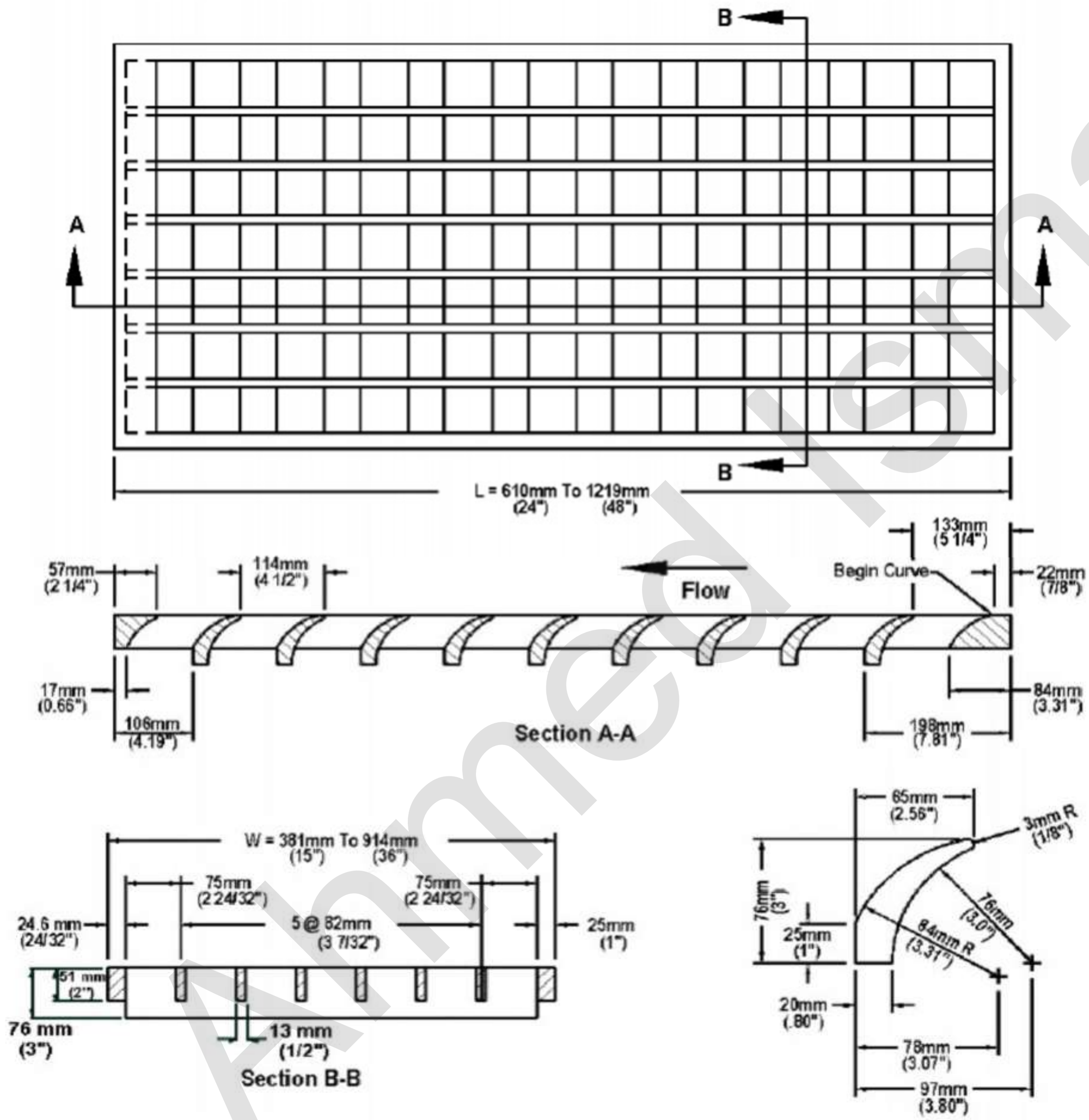


Figure 1-3: Curved Vane Grate

45° – 60 Tilt Bar: 45° tilt-bar grate with 57 mm (2-1/4 in) longitudinal bar and 102 mm (4 in) transverse bar spacing on center (Figure 1-4).

45° – 85 Tilt Bar: 45° tilt-bar grate with 83 mm (3-1/4 in) longitudinal bar and 102 mm (4 in) transverse bar spacing on center (Figure 1-4).

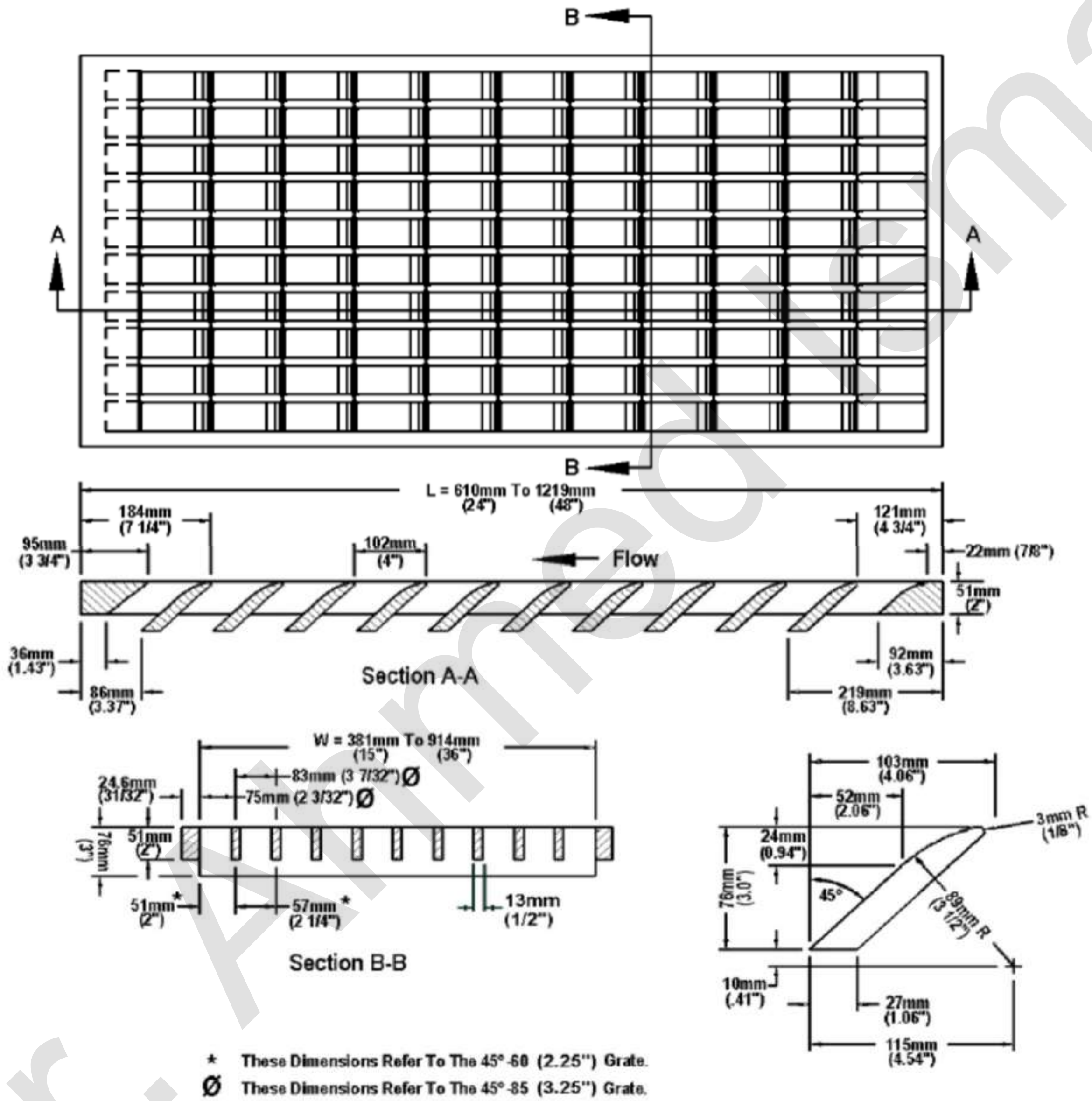


Figure 1-4: 45 – 60-Degree and 45-85-Degree Tilt-Bar Grates

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30° – 85 Tilt Bar: 30° tilt-bar grate with 83 mm (3-1/4 in) longitudinal bar and 102 mm (4 in) transverse bar spacing on center (Figure 1-5).

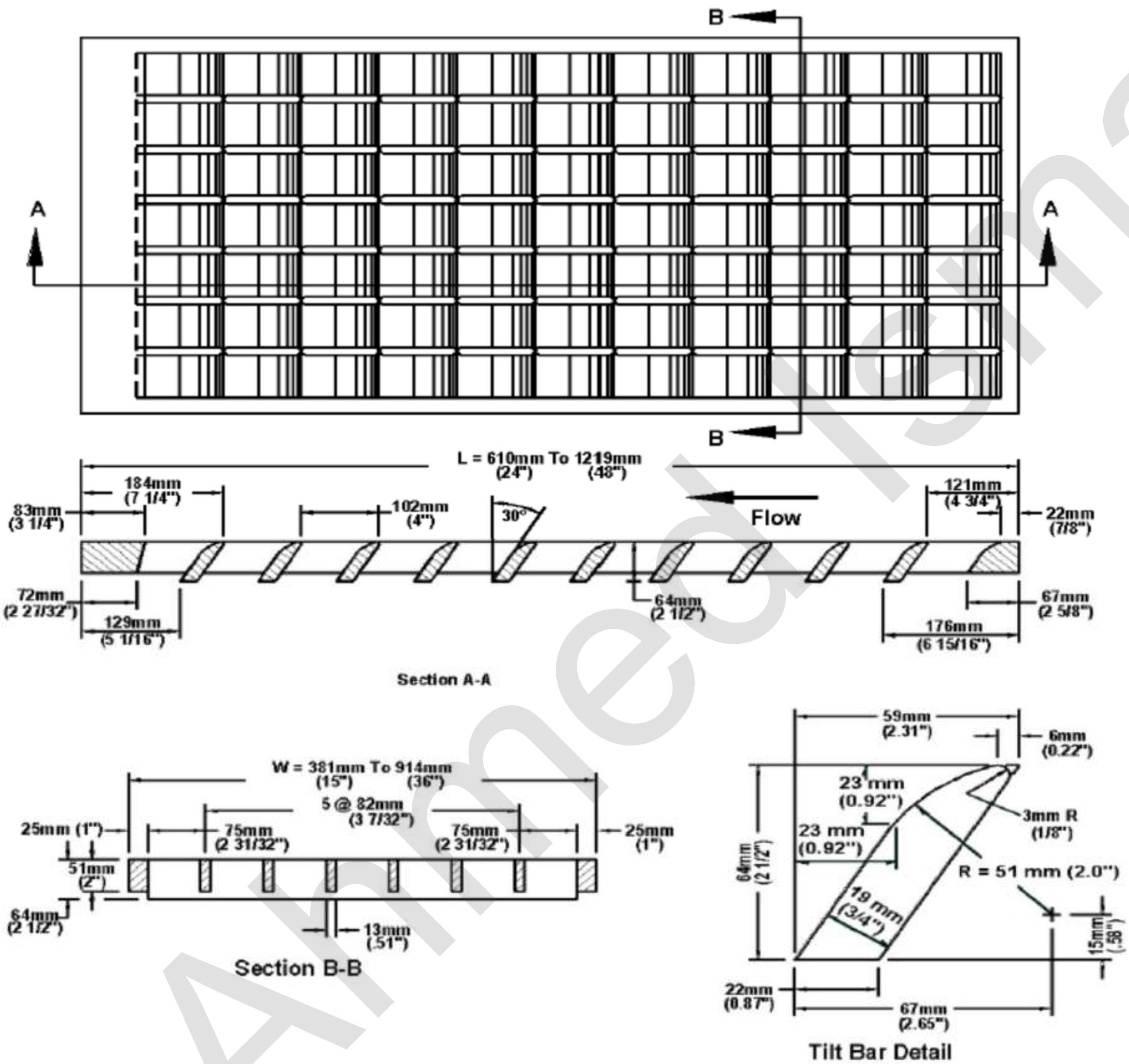

Figure 1-5: 30 – 85-Degree Tilt-Bar Grate

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Reticuline: Honeycomb pattern of lateral bars and longitudinal bearing bars (Figure 1-6).

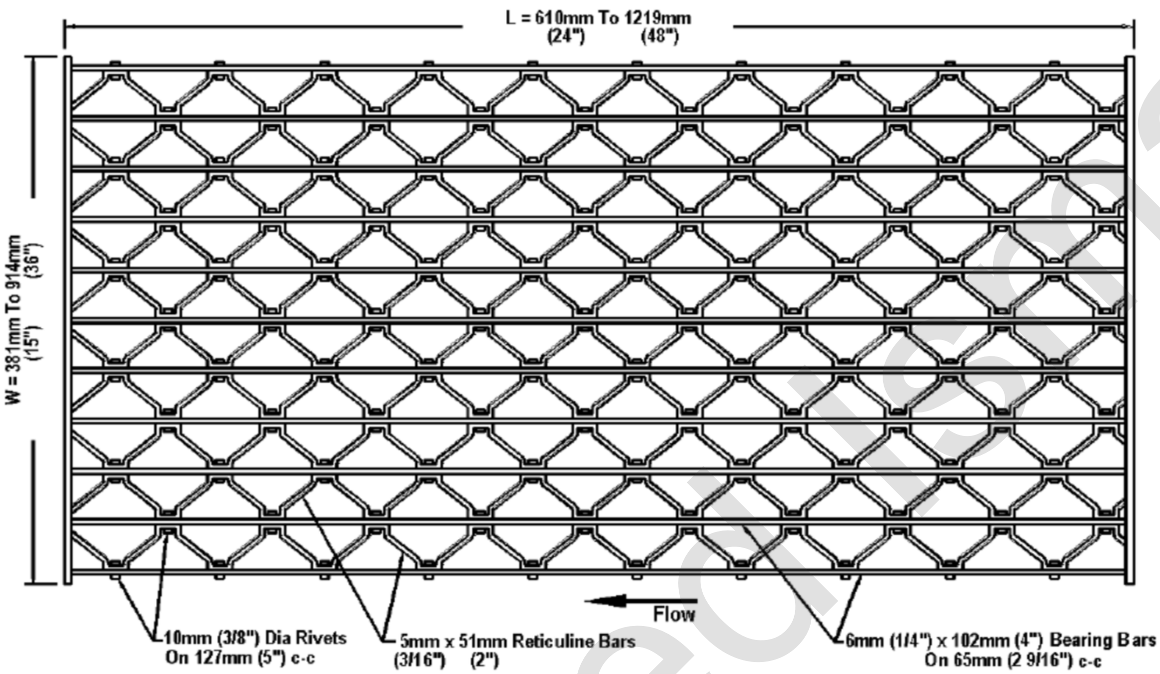

Figure 1-6: Reticuline Grate

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