Chapter-two
Flow Process in Urban Drainage Systems

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Questions

1. What is the flow process ?
2. What is urban drainage system ?

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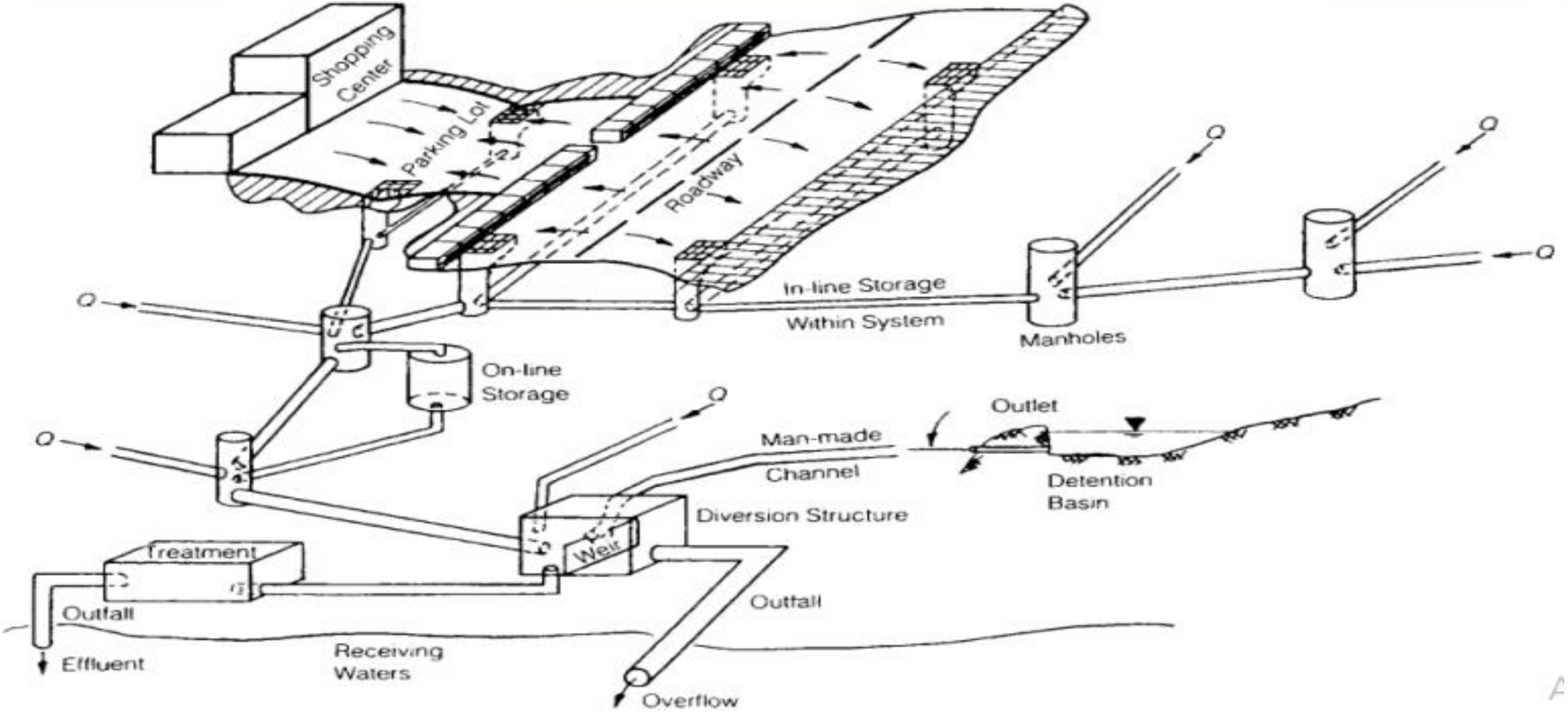

Fig 2.1 (a) showing, principal hydraulic elements in urban storm drainage system

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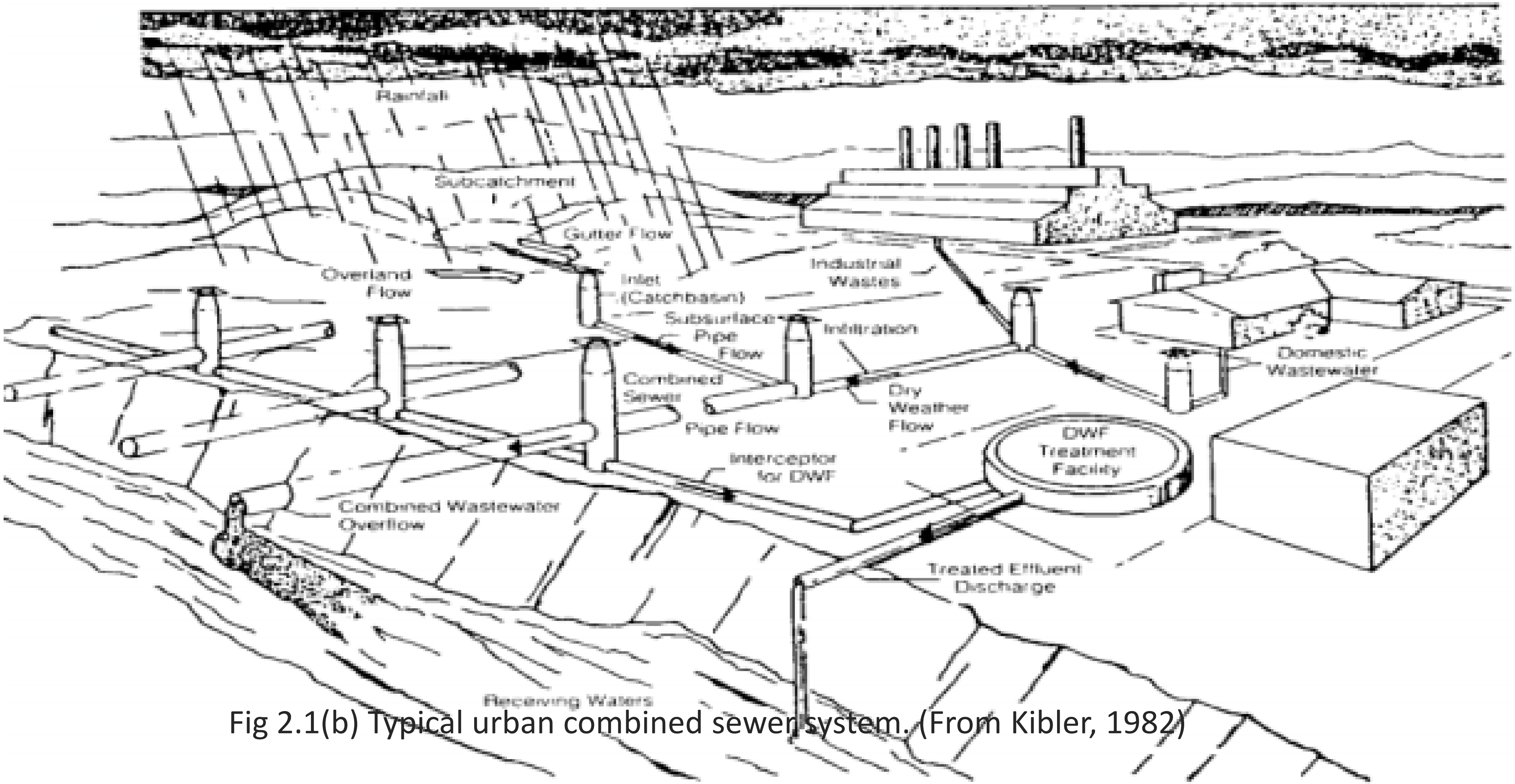

Fig 2.1(b) Typical urban combined sewer system. (From Kibler, 1982)

2.1 Introduction

- Generally speaking urban drainage system consists of three parts:

1) The overland surface flow system

2) The sewer network and

3) The underground porous media drainage system

□Traditionally no design is considered for urban porous media drainage part.

□Recently porous media drainage facilities, such as infiltration trenches have been control designed for flood reduction & pollution control in cities with high land costs.

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- Urban drainage systems: are generally networks of sewers, which carry urban waste water & storm water to one or more terminal points where it is treated and/or discharged to the environment.
- Combined sewer system carry rain & west water together.
- Specifically a storm drain system is defined as a system, that collect, convey & discharges storm water runoff from the drainage basin to designated out flow collection point.

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- What problems of urban drainage systems, is the Hydrologist Expected to solve ?

Problems of urban drainage systems

- From hydraulic engineering view point urban drainage problems can be classified in to two types:

1. Design &
2. Prediction for forecasting or operation

- In design, a drainage facility is to be built to serve all future events not exceeding a specified design hydrologic level.

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- Sewers, ditches, and canals in a drainage network, each has its own time of concentration & design storm.

❖ In the design of a network, all this different rain storms should be considered.

❖ Notice that, the hydrologic requirements for this two types of problems are different.

❖ In case of prediction a given rain storm with its specific temporal & spatial distributions of rainfall is considered.

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- For the design purposes, hypothetical rain storms with assigned design return period or acceptable risk and assumed temporal & special distribution of the rainfall are used.
- In the case of sanitary sewers, for design purpose the problem becomes, the **estimation of the critical runoffs** in both quantity & quality from domestic, commercial & industrial sources over the service period in the future.
- Conventional urban drainage systems are separate (storm-water or west-water) or combined in which case both waste & storm water share the same pipe.

Type	Design purpose	Hydro information sought	Required hydraulic level
Sewers	Pipe size (and slope) determination	Peak discharge, Q_p for design return period	Low
Drainage channels	Channel dimensions	Peak discharge, Q_p for design return period	Low to moderate
Detention/retention storage ponds	Geometric dimensions (and outlet design)	Design hydrograph, $Q(t)$	Low to moderate
Manholes and junctions	Geometric dimensions	Design hydrograph, $Q(t)$	Low to moderate
Roadside gutters	Geometric dimensions	Design peak discharge, Q_p	Low to moderate
Inlet catch basins	Geometric dimensions	Design peak discharge, Q_p	Low
Pumps	Capacity	Design hydrograph	Moderate to high
Control gates or valves	Capacity	Design hydrograph	Moderate to high

(b) Prediction Problems

Type	Purpose	Hydro input	Hydro information sought	Required hydraulic level
Real-time operation	Real-time regulation of flow	Predicted and/or just measured rainfall, network data	Hydrographs, $Q(t, x_i)$	High
Performance evaluation	Simulation for evaluation of a system	Specific storm event, network data	Hydrographs, $Q(t, x_i)$	High
Storm event simulation	Determination of runoff at specific locations for particular past or specified events	Given past storm event or specified input hydrographs, network data	Hydrographs, $Q(t, x_i)$	Moderate-high
Flood level determination	Determination of the extent of flooding	Specific storm hyetographs, network data	Hydrographs and stages	High
Storm runoff quality control	Reduce and control of water pollution due to runoff from rainstorms	Event or continuous rain and pollutant data, network data	Hydrographs $Q(t, x_i)$ Pollutographs, $c(t, x_i)$	Moderate to high
Storm runoff master planning	Long-term, usually large spatial scale planning for stormwater management	Long-term data	Runoff volume Pollutant volume	Low

2.2 Components of urban storm drainage system

- A complete storm drainage system design includes considerations of both major & minor drainage systems.
- The minor system sometimes called "conveyance" system consists of components that have been historically considered as part of the "storm drainage system".

This components include:

- Curbs
  - Gutters
  - Ditches
  - Inlets
  - Access holes
  - Pipes & other conduits
  - Open channels
  - Pumps
  - Detention basins
  - Storm drains
  - Water quality control facilities, etc.

2.2.1 Minor storm drainage system components

- The components of minor storm drainage systems can be categorized by function as, those which:

1) collect storm water runoff from the roadway surface and right-ofway,

2) convey it along and through the right-of the right-way and

3) discharge it to an adequate receiving body without causing adverse on-off-site environmental impacts.

Storm water collection

- Storm water collection is a function of the minor storm drainage system which is accommodated through the use of :

A. Roadside and median ditches,

B. Gutters, and

C. Drainage inlets.

General Design considerations

- The design objective of pavement drainage systems is to keep the spread of water over the pavement below an allowable value for a specified return period.
- Large return periods are used for streets with high traffic volumes, whereas, small return periods are used for low traveled roads.
- Table 2.2 which has been adapted from the Federal Highway Administration (Brown et al. 1996), which suggests design return periods and allowable spreads for various types of roads.

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Table 2.2 Suggested Minimum Design Frequency and Spread (After Brown et al. (1996)

Road Classification	Design Frequency	Design Spread
High volume, divided, or directional		
< 70 km/hr (45mph)	10-year	Shoulder + 1m (3ft)
> 70 km/hr (45mph)	10-year	Shoulder
Sag point	50-year	Shoulder + 1m (3ft)
Collector		
< 70 km/hr (45mph)	10-year	½ driving lane
> 70 km/hr (45mph)	10-year	Shoulder
Sag point	10-year	½ driving lane
Local Streets		
Low ADT*	5-year	½ driving lane
High ADT	10-year	½ driving lane
Sag point	10-year	½ driving lane

Note: ADT, Average Daily Traffic

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- Apart from design return period, roadway geometry plays an important role in pavement drainage.

For instance:

- longitudinal slopes higher than 0.5% are recommended for curbed pavements with an absolute minimum of 0.3%
- Cross-slope of 2% are recommended for most situations, since this slope provides, adequate drainage without a significant effect on driver comfort and safety.
- It may be possible to increase the cross-slope for multilane streets, but slopes beyond 4% shouldn’t be used.

A) Roadside and Median Ditches;

- This are used to intercept runoff and carry it to an adequate storm drain.
- These ditches should have adequate capacity for the design runoff and should be provided to control erosion in ditches, Where design velocities will permit, vegetative linings should be used.

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Fig 2.2 Showing road side median ditch's of storm water collection system

B) Gutters;

- Are used to intercept pavement runoff and carry it along the roadway shoulder to an adequate storm drain inlet.
- Curbs :- are typically installed in combination with gutters where runoff from the pavement surface would erode fill slopes and/or where right-of-way requirements or topographic conditions will not permit the development of roadside ditches.
- Pavement sections are typically curbed in urban settings. Parabolic gutters without curb are used in some urban areas.

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Fig 2.3 b) Showing road side gutter of storm water collection system

Flow in gutters

- Gutter flow calculations are performed to determine the flow depth and spread of water on the shoulder, parking lane, or pavement section under design flow condition.
- The design discharge is often calculated using rational method.
- Although, strictly speaking, the flow in gutter is unsteady and non-uniform, in practice, usually the calculations are performed as if the flow is steady and uniform at the peak design discharge.
- Generally this approaches yields conservative results.
- There are different types of road side gutters with varying geometry, such as triangular, composite, V- shaped and circular as shown in the fig 2.4 below.

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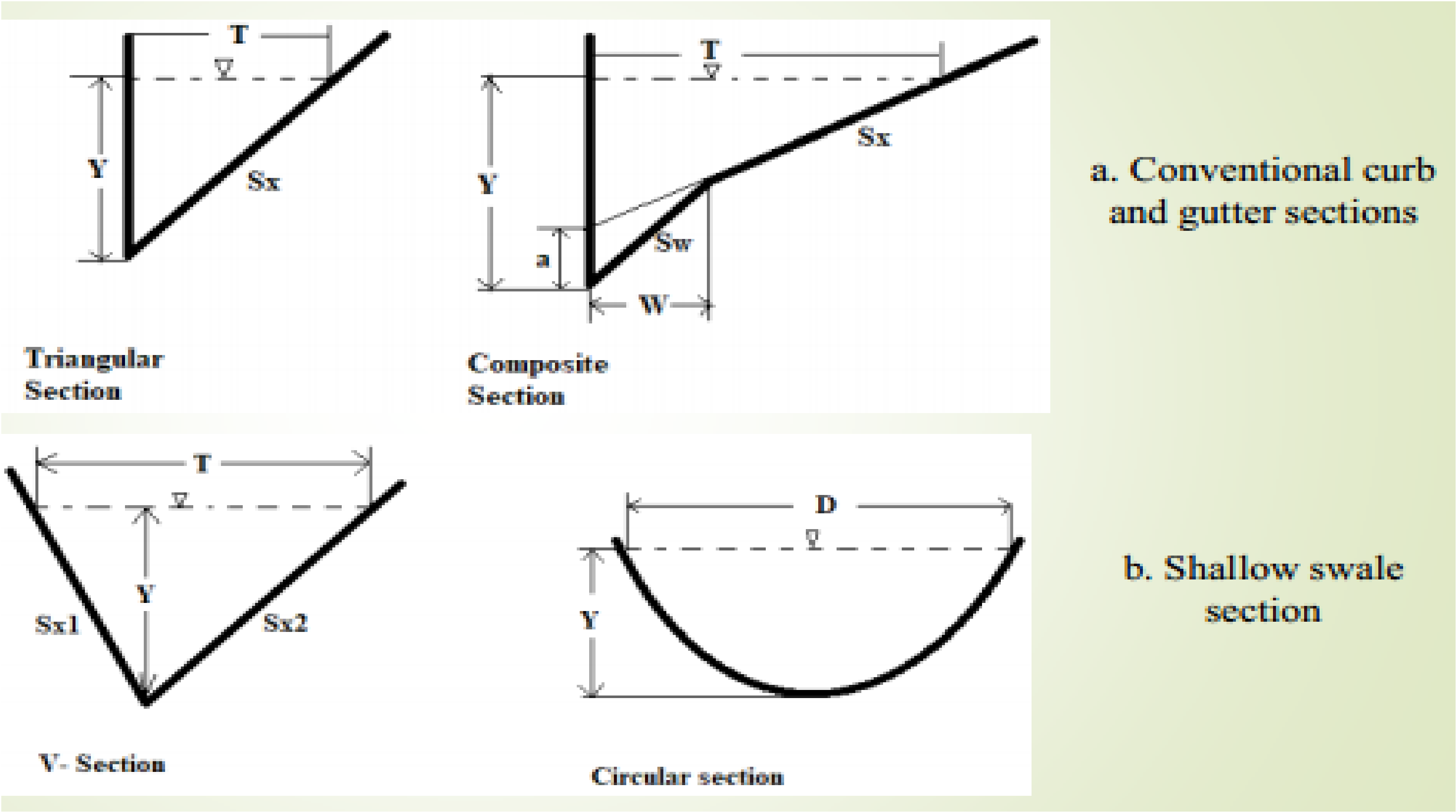

Figure 2.4 Typical Gutter sections

a. Triangular gutters

- The Manning formula is slightly modified for gutter flow to account for the effects of very small hydraulic radius of the flow.
- For the triangular gutter as shown in fig 2.4 above, the modified Manning formula is written as;

Where;
Q = gutter flow,
$\mathbf{k_n}$ = conversion constant (1m1/3/s in metric units and 1.49ft1/3/s in customary U.S. units),
T = Top width,
n = Manning's roughness,
$\mathbf{S_x}$ = Cross slope, and
$\mathbf{S_L}$ = Longitudinal slope.
Obviously, the Top width "T" represents the water spread.

$$Q = \frac{K_n T^{8/3} S_x^{5/3} S_L^{1/2}}{2.64n} \quad (1)$$

$$T = \left[\frac{2.64Qn}{K_n S_x^{5/3} S_L^{1/2}}\right]^{3/8} \quad (2)$$

$$y = S_x T \quad (3)$$

$$Q = \frac{K_n y^{8/3} S_L^{1/2}}{2.64 n S_x} \quad (4)$$

$$A = \frac{1}{2} S_x T^2 \quad (5)$$

Example 1

- A triangular gutter has a longitudinal slope of SL = 0.01, cross-slope of Sx = 0.02, and Manning roughness of n = 0.016. Determine the flow depth and spread at a discharge of 2cfs.

Solution

$$T = \left[\frac{2.64Qn}{K_n S_x^{5/3} S_L^{1/2}}\right]^{3/8} = \left[\frac{2.64(2)(0.016)}{1.49*(0.02)\text{^}1.67*(0.01)\text{^}0.5}\right]^{3/8} = 9.33\text{ft}$$

$$y = S_x T = (0.02)*(9.33) = 0.19\text{ft}$$

b. Composite gutter

For composite gutter section as shown in the figure 2.4 above, the discharge through the gutter is given by;

$$Q = Q_w + Q_s \quad (6)$$

Where,

Q_w = discharge in the depressed section, and,

Q_w = discharge in the section that is not depressed

It can be shown that,

$$Q = \frac{Q_s}{1 - E_0} \quad (7)$$

in which;

$$E_0 = \frac{1}{1 + \frac{S_w/S_x}{\left[1 + \frac{S_w/S_x}{(\frac{T}{W} - 1)}\right]^{8/3} - 1}} \quad (8)$$

- Where;

$$S_w = S_x + \frac{a}{W} \quad (9)$$

- All geometric variables are depicted in figure 2.4 (a).
- Thus, alternatively, a graphical solution to "Q" and "E_0" can be obtained using figure 2.5 "a" and "b" below.
- Also, notice that from the geometry,

$$y = a + TS_x \quad (10)$$

$$A = \frac{1}{2}S_xT^2 + \frac{1}{2}aW \quad (11)$$

- Where, y = depth of flow at the curb and A= flow area

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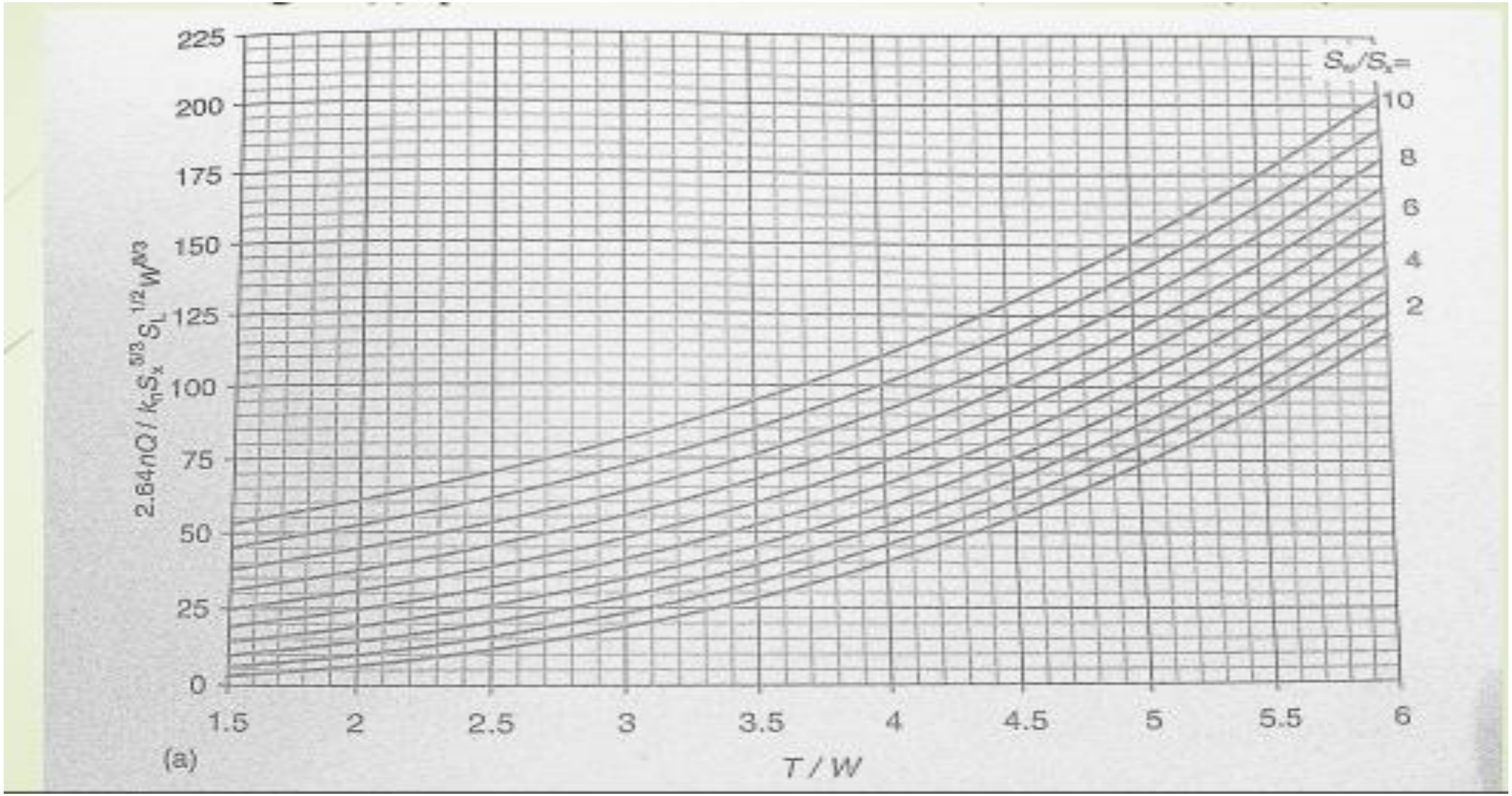
Fig 2.5(a) spread calculations for T/W< 6, From Akan (2000)



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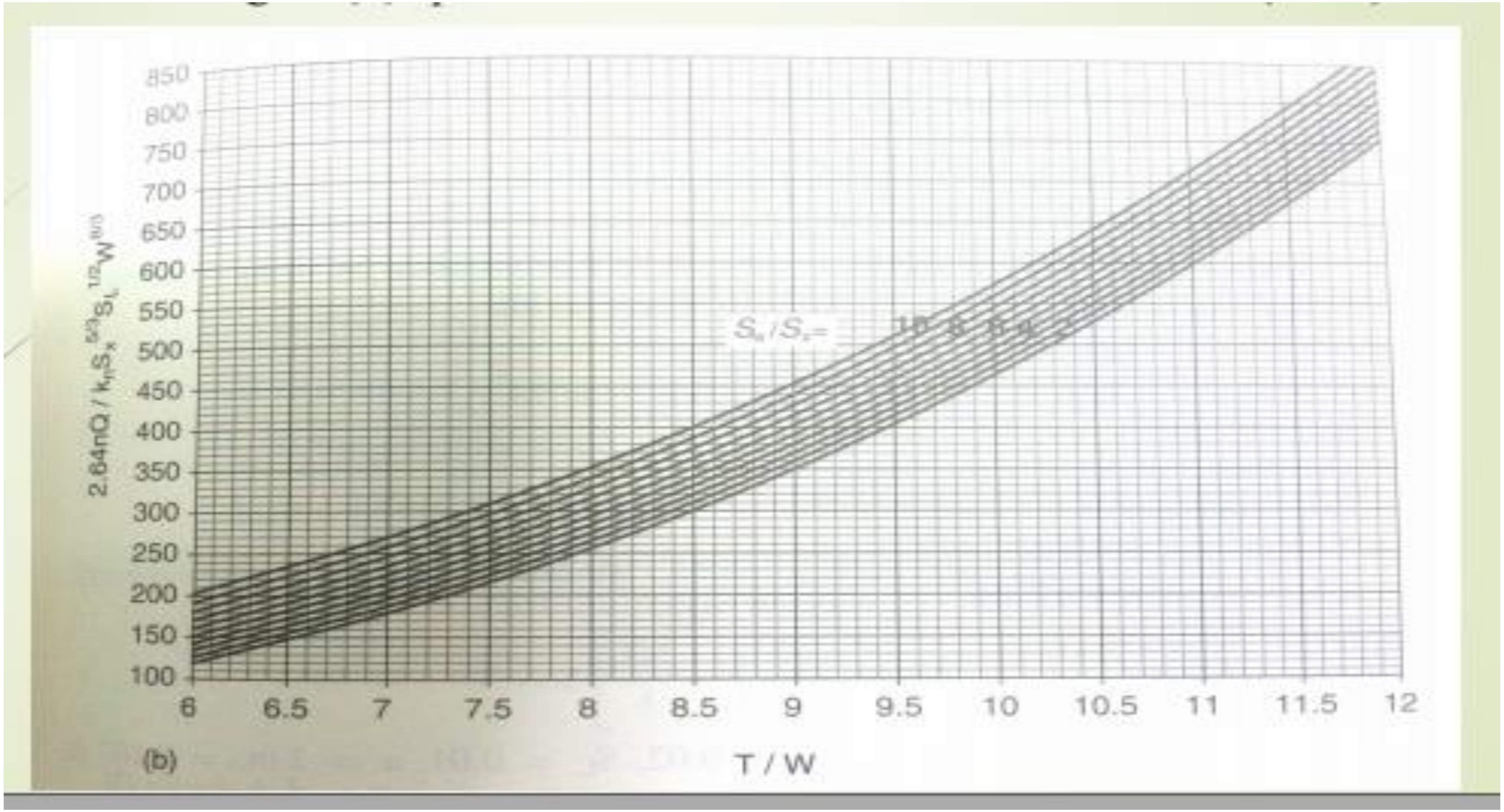

Fig 2.5(b) spread calculations for T/W>6. From Akan (2000)

Example 2

- A composite gutter section has the dimensions W = 0.5m, SL = 0.008, Sx= 0.02, and a = 0.05m. The Manning roughness factor is n = 0.016.
- Determine the discharge in the gutter at a spread T = 2m.

Solution

- First calculate the cross-slope of the depressed gutter $\mathbf{S_w}$ by using equation 7

$$S_W = S_x + \frac{a}{W} = 0.02 + 0.05/0.5 = \mathbf{0.12}$$

- Also, with reference to fig 2.5

$$Ts = T - W = 2 - 0.5 = \mathbf{1.5m}$$

- To find Qs, equation 1 can be rewritten for the triangular portion of the composite gutter having a top width **Ts** and evaluated as;

$$Q = \frac{K_n {T_s}^{8/3} S_x^{5/3} S_L^{1/2}}{2.64n} = \frac{(1)*(1.5)^{\frac{8}{3}}*(0.02)^{\frac{5}{3}}(0.008)^{\frac{1}{2}}}{2.64*0.016} = \mathbf{0.0091m^3/s}$$

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- Note that, kn = $1m^{1/3}/s$ is used for the metric system.
- Now with Sw/Sx = 0.12/0.02 = **6**,
- T/W = 2/0.5 = **4** and (T/W – 1) = 4-1= **3**
- Then using equation 7,

$$E_0 = \frac{1}{1+\frac{S_w/S_x}{\left[1+\frac{S_w/S_x}{(\frac{T}{W}-1)}\right]^{8/3}-1}} = \frac{1}{1+\frac{6}{\left[1+\frac{6}{3}\right]^{8/3}-1}} = \mathbf{0.75}$$

- Finally, by using equation 6,

$$Q = \frac{Q_S}{1-E_0} = \frac{0.0091}{1-0.75} = \mathbf{0.036\ m^3/s}$$

- Alternatively, we can obtain a solution to this problem by using fig 2.5 with T/W = 4 and S_w/S_x = 6, the figure yields,

$$\frac{2.64Qn}{K_n S_x^{5/3} S_L^{1/2} W^{8/3}} = \mathbf{74}$$

- Solving this expression for Q yields

$$Q = \frac{(74)*(0.02)^{\frac{5}{3}}(0.008)^{\frac{1}{2}}(0.5)^{\frac{8}{3}}}{2.64*(0.016)} = \mathbf{0.036m^3/s}$$

Example 3

- A composite gutter section has Sx = 0.02, SL = 0.01, a = 2 in =0.167ft, n = 0.016 and W = 2ft. Determine the spread T at Q = 2.5cfs.

Solution

- Solving this problem by equation 6 and 7 requires a trial and error procedure since the equations are implicit in T.
- In the trial-and-error procedure, we first guess the value of T and calculate the value of Q by using equation 7 and 6.
- If the calculated Q is the same as the given Q, then the guessed value of T is correct. Otherwise, we repeat the same procedure using another guess for T.
  - We can eliminate the trial and error procedure by using figure 2.5.
  - Here, we first calculate Sw by using equation 8.

$$\mathbf{Sw} = 0.02 + 0.167/2 = 0.104$$

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- Then Sw/Sx = 0.104/0.02 = **5.2**
- Now we evaluate the dimensionless discharge parameter:

$$\frac{2.64Qn}{K_n S_x^{5/3} S_L^{1/2} W^{8/3}} = \frac{2.64 * (0.016) * (2.5ft3/s)}{(1.49ft^{1/3}/s) * (0.02)^{\frac{5}{3}} * (0.01)^{\frac{1}{2}} * (2)^{\frac{8}{3}}} = \mathbf{76}$$

- Using this value, with Sw/Sx = **5.2**,
- We obtain T/W = **4.25**
- from figure 2.5.

Therefore, T = 4.25 (2) = **8.5ft.**

c. Swale section

- V-shaped and circular swale sections are used to convey runoff from pavements where curbs are not used.
- The flow within a V-section can be calculated using equation 6.1 and 6.2 with.

$$S_x = \frac{S_{X1} S_{X2}}{S_{X1} + S_{X2}} \quad (12)$$

- The flow in a circular swale or gutter can be calculated using (Brown et al. 1996)

$$\frac{Y}{D} = kc\left(\left(\frac{Qn}{D^{2.67} S_L^{0.5}}\right)\right)^{0.488} \quad (13)$$

Where Y = flow depth (m or ft),

D = diameter of circular gutter (m or ft),

S_L = longitudinal Slope and

K_c = 1.179 in metric units and 0.972 in customary U.S. units.

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- The top width (T) of the flow within the circular section is expressed as

$$T = 2\left(\frac{D^2}{4} - \left(\frac{D}{2} - Y\right)^2\right)^{1/2}$$

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Example 4

A V- section swale has $\mathbf{S_{x1} = 0.04}$, $\mathbf{S_{x2} = 0.06}$, $\mathbf{n = 0.016}$, $\mathbf{S_L = 0.01}$, and $\mathbf{T = 8ft}$. Determine the maximum discharge this swale can convey without water spreading over the pavement surface. Also determine the depth of flow.

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- For the flow not to spread over the pavement, the top width should not exceed 8ft. Using equation 11, we find

$$S_x = \frac{(0.04) * (0.06)}{0.04 + 0.06} = \mathbf{0.024}$$

- Now by using by using equation 1, we obtain

$$Q = \frac{(1.49)*(8ft)^{\frac{8}{3}}*(0.024)^{\frac{5}{3}}(0.01)^{\frac{1}{2}}}{(2.64)*(0.016)} = \mathbf{1.8ft^3/s}$$

Also, by using equation 3, we get,

$$Y = (0.024)*(8) = \mathbf{0.19ft}$$

Example 5

- A V-section swale, will be used in an **8ft** shoulder to convey **2ft³/s**. the longitudinal slope is $\mathbf{S_L}$ **= 0.008** and the Manning roughness factor **n = 0.016.** Determine the cross-slopes and the depth of the swale.

Solution

- Solving equation 1 for $\mathbf{S_x}$ yields,

$$S_x = \left(\frac{2.64 * (0.016)(2)}{(1.49)(8)^{\frac{8}{3}}(0.008)^{\frac{1}{2}}}\right)^{3/5} = \mathbf{0.027}$$

- Now let us assume that Sx1 = Sx2. Then from equation 12, we have

$$0.027 = \frac{(S_{x1})^2}{2Sx_1} = \frac{S_{x1}}{2}$$

And $S_{x1} = 2(0.027) = 0.054$.

Also, from equation 3, Y = (0.027)*(8) = 0.216~ **0.22ft.**

Example 6

- A circular swale with a diameter of **D = 5ft** is to carry **Q = 1.5cfs.** The Manning roughness factor is **n = 0.016**, and the longitudinal slope $\mathbf{S_L}$ = **0.01**. Determine the required depth and the top width of the swale.

Solution

$$Y = (5)(0.972)\left(\left(\frac{(1.5)(0.016)}{(5)^{2.67}(0.01)^{0.5}}\right)\right)^{0.488} = 0.3ft$$

$$T = 2\left(\frac{5^2}{2} - \left(\frac{5}{2} - 0.3\right)^2\right)^{1/2} = 2.38ft$$

C) Drainage inlets

- Are the receptors for surface water collected in ditches and gutters, and serve as the mechanism whereby surface water enters storm drains.
- When located along the shoulder of the roadway, storm drain inlets

are sized and located to limit the spread of surface water on to travel lanes.

- The term “inlets”, as used here, refers to all types of inlets such as grate inlets, curb inlets, combination inlets and slotted inlets, as shown in fig 2.6 below.

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- Thus, the primary purpose of inlets is to collect storm water runoff from pavements and discharge it in to an underground conveyance system.
- Inlets can be installed, with or without a depression of the gutter.

- The efficiency of inlets is defined as,

$$E = \frac{Q_i}{Q} \qquad (15)$$

Where, E = efficiency

Q = total gutter flow rate, and

Q_i = intercepted flow rate,

- The flow that is not intercepted by an inlet is called carryover or bypass.
- By definition,

$$Q_b = Q - Q_i \qquad (16)$$

Where, Q_b = carryover (bypass) flowrate.

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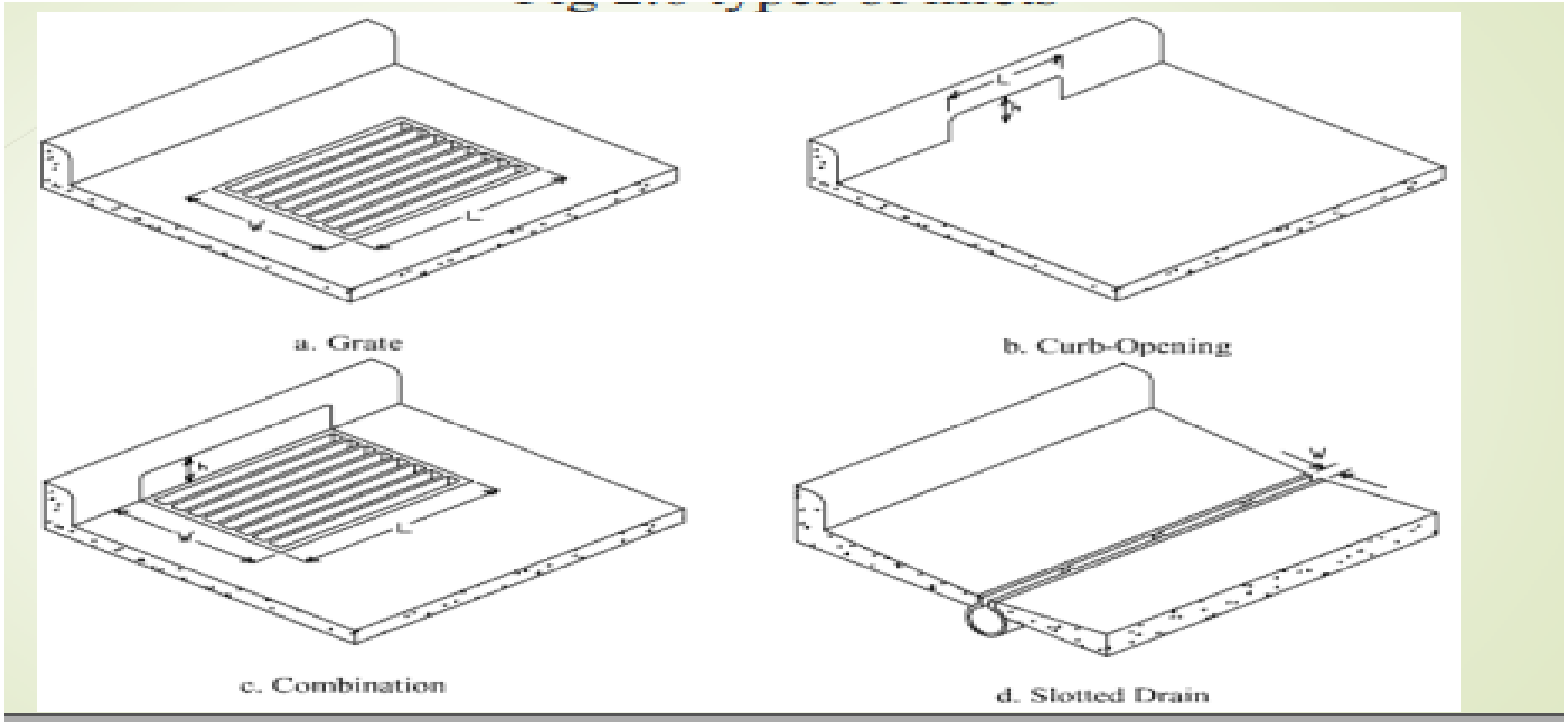
Fig 2.6 types of inlets



i. Grate inlet

- Grate inlets perform satisfactorily over a wide range of gutter grades.
- Grate inlets generally lose capacity with increase in grade, but to a lesser degree than curb-opening inlets.
- The principal advantage of grate inlets is that they are installed along the roadway where the water is flowing.
- Their principal disadvantage is that they may be clogged by floating trash or debris.
- For safety reasons, preference should be given to grate inlets where out-of-control vehicles might be involved.
- Additionally, where bicycle traffic occurs, grates should be bicycle safe.

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Fig 2.7 grate inlet at Kulfo bridge

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- To determine the efficiency of a grate inlet, the total gutter flow is treated as having two parts:
  1. Frontal flow and
  2. Side flow
- The frontal flow is the portion of the total gutter flow within the width of the inlet. It is expressed as:

$$Q_w = Q\left[1 - \left(1 - \frac{W}{T}\right)^{2.67}\right] \quad (17)$$

Where Q_w = frontal discharge,

W = width of the depressed gutter or inlet, and

T = total spread of water in the gutter

Also,

$$Q_s = Q - Q_w \quad (18)$$

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- Where Q_s = side discharge corresponding to the flow outside the width of the inlet (T - W)

- The ratio R_f of frontal intercepted flow to total frontal flow is expressed as;

$$R_f = \frac{Q_{wi}}{Q_w} = 1 - K_f (V - V_0) \quad \text{for } V > V_0$$ 19a

$$R_f = 1 \text{ for } V \leq V_0$$ 19b

Where,

K_f = conversion (0.295s/m in metric units and 0.09s/ft in customary U.S. units),

Q_{wi} = frontal flow intercepted,

V = velocity of flow in the gutter, and

V_0 = splashover velocity

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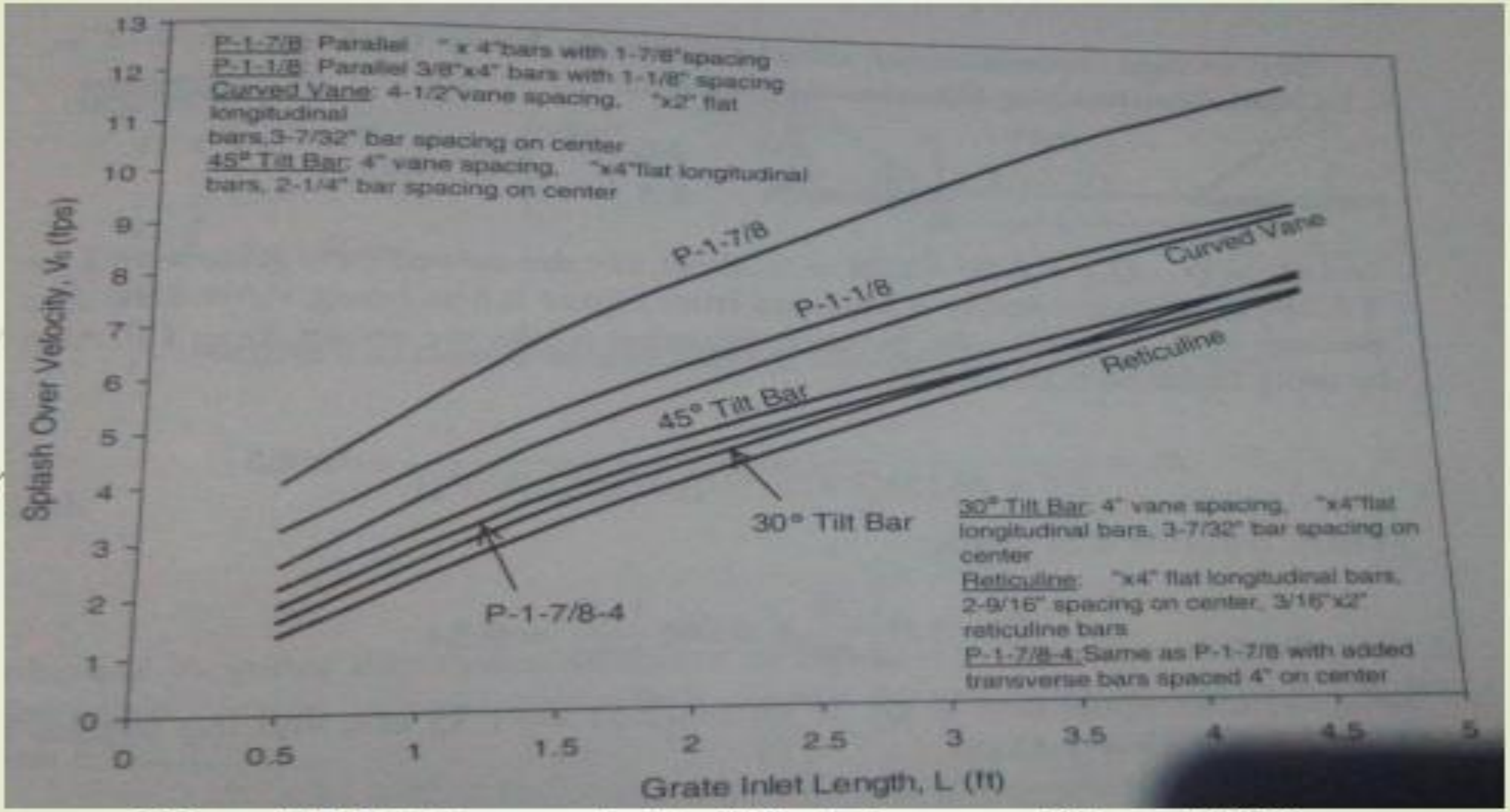

Figure 2.9 Splashover velocity. After Johnson and Chang (1984)

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- Splashover velocity is the minimum velocity that will cause some water to shoot over the inlet.
- This velocity depends on the gutter length and type. figure 2.9 displays the **splashover velocities** for several standard grates tested by the Federal Highway Administration.
- The ratio R_{fs} of intercepted side flow to total side flow is expressed as

$$R_s = \frac{Q_{si}}{Q_s} = \frac{1}{1+((K_s)(V)^{1.8})/(Sx)(L)^{2.3}} \quad (20)$$

Q_{si} = side flow intercepted,

K_s = conversion factor (0.0828 $m^{0.5}/s^{1.8}$ for metric and 0.15 $ft^{0.5}/s^{1.8}$ for U.S.), and

L = length of grate

- The efficiency **"E"** of a grate inlet is evaluated by using

$$E = R_f \frac{Q_{wi}}{Q} + R_s \frac{Q_{si}}{Q_s} \quad (21)$$

Example 7

A triangular gutter with $\mathbf{S_X = 0.02}$, $\mathbf{S_L = 0.01}$, and $\mathbf{T = 8.5ft}$ carries $\mathbf{Q = 2.5cfs.}$ A curved vane grate placed in this gutter has $\mathbf{W = 2ft}$ and $\mathbf{L = 2ft.}$ Determine the efficiency of this grate.

Solution

- First, determine the flow area by using equation 5

$$A = \tfrac{1}{2}(0.02)(8.5)^2 = 0.72\text{ft}^2$$

- The average cross-sectional velocity becomes

$$V = Q/A = 2.5/0.72 = 3.47\text{ft/s}$$

- Also, by using equation 17 we have,

$$Q_w = Q\left[1 - \left(1 - \frac{W}{T}\right)^{2.67}\right]$$

$$Q_w = 2.5\left[1 - \left(1 - \frac{2}{8.5}\right)^{2.67}\right] = \mathbf{1.28ft^3/s}$$

- Then,

$$Q_S = Q - Q_W = 2.5 - 1.28 = \mathbf{1.22ft^3/s}$$

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- For curved vane grate with L = 2ft, the splashover velocity is obtained from figure 2.9, as being Vo = 5.95ft/s
- Because $V_O > V$ in this case by using equation 19b, we obtain $R_f = 1$.
- Also by using equation 20 we find, R_s

$$R_s = \frac{Q_{si}}{Q_s} = \frac{1}{1+((K_s)(V)^{1.8})/(Sx)(L)^{2.3}} = \frac{1}{1+[((0.15)(3.47)^{1.8})/(0.02)(2)^{2.3}]} = \mathbf{0.065}$$

- Finally, equation 21 yields,

$$E = 1\frac{1.28}{2.5} + 0.065\frac{1.22}{2.5} = \mathbf{0.54}$$

- Thus, the intercepted flow is

$$Q_i = (E)(Q) = (0.54)(2.5) = \mathbf{1.35ft^3/s}$$

- The bypass flow (Q_b) is

$$Q_b = Q - Q_i = 2.5 - 1.35 = \mathbf{1.15ft^3/s}$$

ii. Curb-opening Inlets

- Curb-opening inlets are most effective on flatter slopes, in sags, and with flows that typically carry significant amounts of floating debris.
- The interception capacity of curb-opening inlets decreases as the gutter grade steepens.
- Consequently, the use of curb-opening inlets is recommended in sags and on grades less than 3 percent.
- There advantage is that, they are less susceptible toclogging and bicycle safe.

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Fig 2.10 Curb opening inlet

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- The efficiency of a curb opening inlet is calculated as:

$$E = \left[1 - \left(1 - \frac{L}{L_T}\right)^{1.8}\right] \quad \text{for } L < L_T \qquad (22a)$$

$$E = 1 \quad \text{for} \quad L \geq L_T \qquad (22b)$$

Where,

L = curb opening length

L_T = curb opening length required **to capture 100%** of gutter flow

And

$$L_T = K_C Q^{0.42} S_L^{\ 0.3} \left(\frac{1}{nS_X}\right)^{0.6} \qquad (23)$$

Where,

$K_C = 0.817\ s^{0.42}/m^{0.26} = 0.6\ s^{0.42}/ft^{0.26}$

Cont…

- For a depressed curb-opening inlet as shown in figure 2.11

$$L_T = K_C Q^{0.42} S_L^{\ 0.3} \left(\frac{1}{nS_e}\right)^{0.6} \quad (24)$$

$$S_e = S_x + \frac{a}{W} E_0 \quad (25)$$

- Where a = gutter depression as shown in figure 2.11.
- The ratio of flow in the depressed section to total gutter flow can be calculated by equation 8.

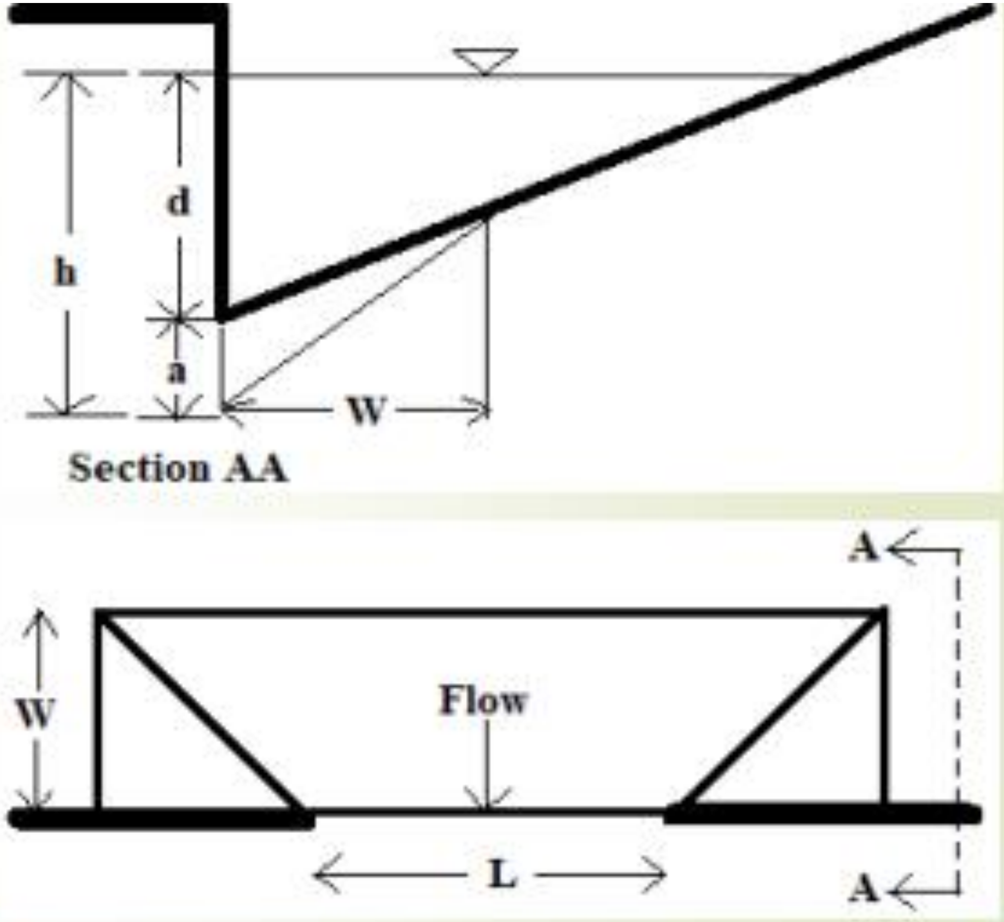


Figure 2.11 depressed curb opening after Johnson and Chang (1984)

Example 8

- A curb-opening inlet is placed in a triangular gutter that has a longitudinal slope of
- SL = 0.01, cross-slope of SX = 0.02, and Manning roughness factor of n = 0.016. The curb-opening inlet has a length of L = 10ft. Determine the flow intercepted by the curb-opening inlet when the gutter discharge is Q = 2cfs.

Solution

$$L_T = K_C Q^{0.42} S_L^{\ 0.3}\left(\frac{1}{nS_X}\right)^{0.6} = (0.6)(2)^{0.42}(0.01)^{0.3}\left(\frac{1}{(0.016)(0.02)}\right)^{0.6} = \mathbf{25ft}$$

$$E = \left[1-\left(1-\frac{L}{L_T}\right)^{1.8}\right] = \left[1-\left(1-\frac{10}{25}\right)^{1.8}\right] = 0.6$$

- Therefore, the intercepted flow (Q_i) is

$$Q_i = (E)(Q) = (0.6)(2) = \mathbf{1.2\ ft^3/s}$$

- The bypass flow (Q_b) is

$$Q_b = Q - Q_i = 2ft3/s - 1.2\ cfs = \mathbf{0.8\ ft^3/s}$$

Example 9

- A composite gutter section considered in example 2 has the dimensions W = 0.5m, SL = 0.008, a = 0.05m, and Sx = 0.02 and a Manning roughness factor of n = 0.016. It was determined in the example that at a spread of T = 2 m, the total gutter discharge was Q = 0.036m3/s and the frontal to total flow ratio was E0 = 0.75. Determine the efficiency of a curb opening inlet placed in the composite gutter if the length of the inlet is L = 1.75m.

Solution

$$S_e = S_x + \frac{a}{W} E_0 = 0.02 + \frac{0.05}{0.5}(0.75) = \mathbf{0.095}$$

$$L_T = (0.817)(0.036)^{0.42}(0.008)^{0.3}\left(\frac{1}{(0.016)(0.095)}\right)^{0.6} = \mathbf{2.3m}$$

$$E = \left[1 - \left(1 - \frac{L}{L_T}\right)^{1.8}\right] = \left[1 - \left(1 - \frac{1.75}{2.3}\right)^{1.8}\right] = 0.92$$

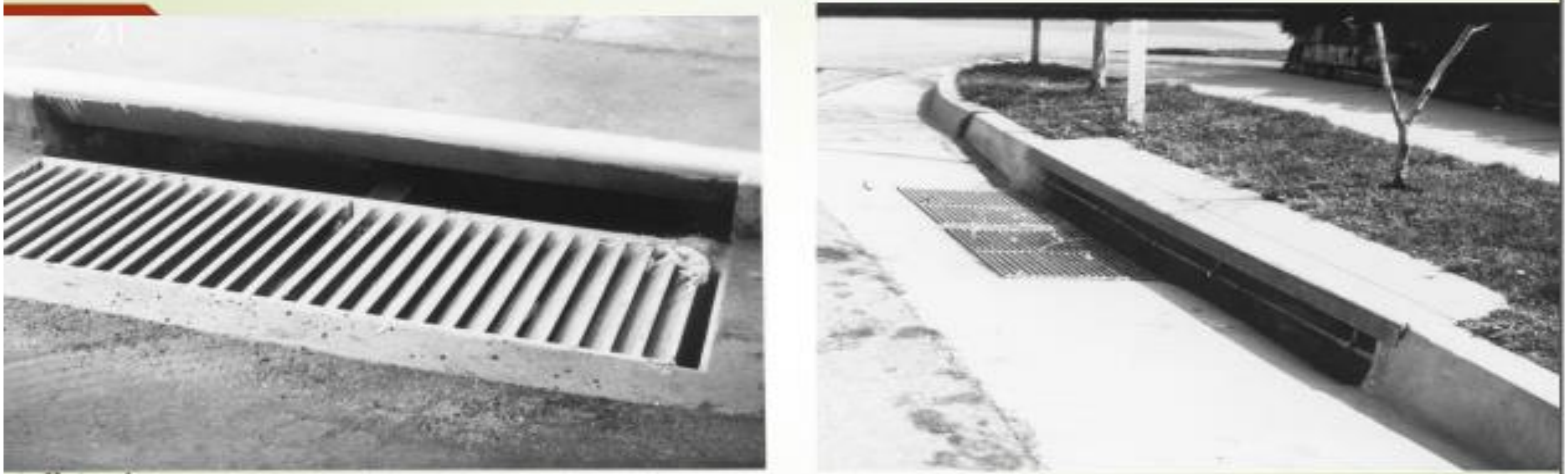
$$Q_i = (E)(Q) = (0.92)(0.036) = \mathbf{0.033\ m^3/s}$$

iii. Combination inlets

- Combination inlets provide the advantages of both curb opening and grate inlets.
- This combination results in a high capacity inlet that offers the advantages of both grate and curb-opening inlets.
- When the curb-opening precedes the grate in a "sweeper“ configuration, the curb-opening inlet acts as a trash interceptor during the initial phases of a storm.
- Used in a sag configuration, the sweeper inlet can have acurb opening on both sides of the grate.

Cont…

Fig 2.12 Combination inlet



A. Combination curb-opening, 45 degree tilt-bar grate inlet

B. Sweeper combination inlet

Example 10

- A combination inlet is installed in a triangular gutter carrying a discharge of 7cfs. The gutter is characterized by SL = 0.01, Sx = 0.025, n = 0.016.the curb opening is 10ft long and the grate is a 2-ft by 2-ft reticu line grate. An 8ft long portion of the curb opening is upstream of the grate. Determine the flow intercepted by this combination inlet.

Solution

- We first consider the upstream portion of the combination inlet. By using equation 23 and 22a respectively, we obtain

$$L_T = (0.6)(7)^{0.42}(0.01)^{0.3}\left(\frac{1}{(0.016)(0.025)}\right)^{0.6} = \mathbf{37}$$

$$E = \left[1-\left(1-\frac{L}{L_T}\right)^{1.8}\right] = \left[1-\left(1-\frac{8}{37}\right)^{1.8}\right] = \mathbf{0.36}$$

- Thus, the 8-ft-long portion of the curb opening intercepts

$$(0.36)(7\text{ft}^3/\text{s}) = \mathbf{2.5ft^3/s}$$

Cont…

- The remaining flow is

$$7 - 2.5 = \mathbf{4.5\ ft^3/s}$$

- The spread corresponding to this discharge is calculated using equation 2 as,

$$T = \left[\frac{2.64Qn}{K_n S_x^{5/3} S_L^{1/2}}\right]^{3/8} = \left[\frac{2.64(4.5)(0.016)}{1.49*(0.025)^{1.67}*(0.01)^{0.5}}\right]^{3/8} = \mathbf{11\ ft}$$

- Now, we will calculate, the flow intercepted by the grate. By using equation 17, we have,

$$Q_w = Q\left[1 - \left(1 - \frac{W}{T}\right)^{2.67}\right] = 4.5\left[1 - \left(1 - \frac{2}{11}\right)^{2.67}\right] = \mathbf{1.9\ ft^3/s}$$

$$Q_S = Q - Q_W = 4.5 - 1.9 = \mathbf{2.6 ft^3/s}$$

- The splashover velocity for the grate is Vo = **4.2ft/s** from figure 2.9

Cont…

- Also from equation 5, the flow area just upstream of the grate is

$$A = ½ (0.025)(11)^2 = \mathbf{1.5ft^2}$$

- Likewise, $V = Q/A = \frac{4.5ft^3/s}{1.5ft^2} = \mathbf{3ft/s}$
- Because, $V < Vo, \quad R_f = 1$

$$R_s = \frac{1}{1+[((K_s)(V)^{1.8})/(Sx)(L)^{2.3}]} = \frac{1}{1+[((0.15)(3)^{1.8})/(0.025)(2)^{2.3}]} = \mathbf{0.1}$$

Then, from equation 21, the efficiency of the grate is

$$E = 1\frac{1.9}{4.5} + 0.1\ \frac{2.6}{4.5} = \mathbf{0.48}$$

The flow intercepted by the grate becomes,

$$Q_i = (E)(Q) = (0.48)(4.5) = \mathbf{2.2\ ft^3/s}$$

The total flow intercepted by the combination inlet is then, $2.5ft^3/s + 2.2ft^3/s = \mathbf{4.7ft^3/s}$

The overall efficiency (E) $= 4.7/7 =$ **0.67** and the bypass flow (Q_b) is $7 - 4.7 = \mathbf{2.3ft^3/s}$

iv. Slotted inlets

- Slotted inlets can be used in areas where it is desirable to intercept sheet flow before it crosses onto a section of roadway.
- Their principal advantage is their ability to intercept flow over a wide section.
- However, slotted inlets are very susceptible to clogging from sediments and debris, and are not recommended for use in environments where significant sediment or debris loads may be present.
- Slotted inlets on a longitudinal grade do have the same hydraulic capacity as curb openings when debris is not a factor.

Cont…

Figure 2.13 slotted inlets

- Thus, the flow interception capabilities of slotted inlets are similar to those of curb opening inlets provided that the slot width is grater than **4.5cm** or **1.75in**.
- Equations 22 to 25 are used to calculate the efficiency of slotted inlets

Storm water conveyance

- Upon reaching the main storm drainage system, storm water is conveyed along and through the right-of-way to its discharge point via storm drains connected by access holes or other access structures.
- In some situations, storm **water pump stations** may also be required as a part of the conveyance system (like in areas where gravity drains are impossible or economical.) **Storm drains;**
- Are defined as that portion of the storm drainage system that receives runoff from inlets and conveys the runoff to some point where it is discharged into a channel, water body, or other piped system.
- Storm drains can be closed conduit or open channel, they consist of one or more pipes or conveyance channels connecting two or more inlets.

Cont…

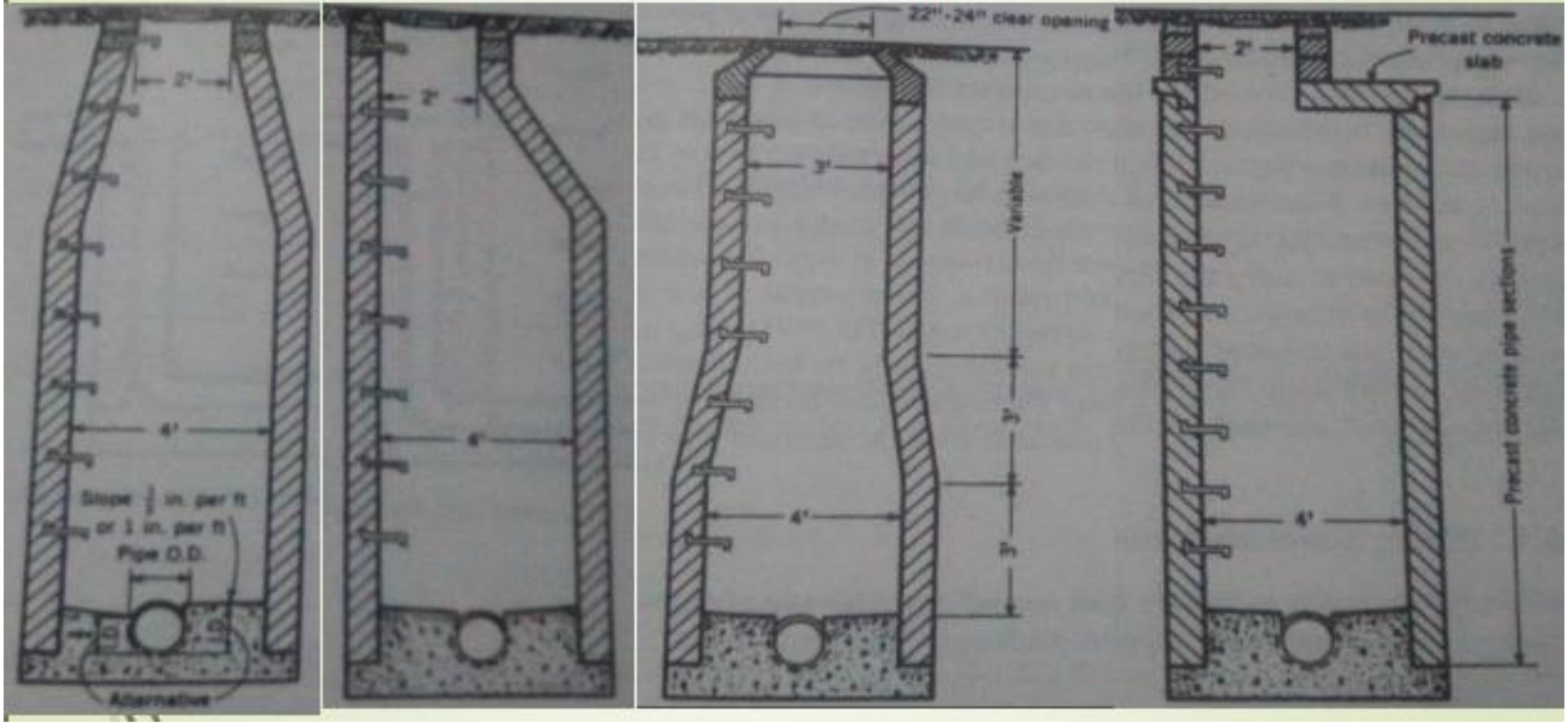
- Access holes, junction boxes, and inlets serve as access structures and alignment control points in storm drainage systems.
- Critical design parameters related to these structures include access structure spacing and storm drain deflection spacing limits are often dictated by maintenance activities.
- In addition, these structures should be located at the intersections of two or more storm drains when there is change in the pipe size, and at changes in alignment (horizontal or vertical).

Cont…

- Manholes (access chambers) provide convenient access to the storm sewer system for inspection and maintenance, and they provide ventilation.
- Manholes also serve as flow junctions, and mostly made of precast or cast-in-place concrete.
- Generally, they are used to transition from one pipe to the other.
- Typical manhole configurations are as shown in figure 14.
- Common manhole depths range from **1.5-4m(5-13ft)** and typical diameters are **1.2-1.5m(4-5ft)**
- They are required where two or more storm drains converge, pipe sizes change, or a change in alignment or grade occurs.
- Also, manholes are **placed every 100m** or more along straight sections of small diameter pipes for maintenance purposes.

Cont…

Figure 14. Manhole configuration from American Society of civil engineers



Storm water Discharge controls

- Storm water discharge controls: are often required to off-set potential runoff quantity and/or quality impacts
- Water quantity controls include: detention/retention facilities. Water quality controls include extended detention facilities as well as other water quality management practices. Detention/retention facilities
- Are used to control the quantity of runoff discharged to receiving waters.
- A reduction in runoff quantity can be achieved by the storage of runoff in detention/retention basins, storm drainage pipes, swales and channels.

2.2.2 Major storm drainage system

- The major systems provides overland relief for storm water flows exceeding the capacity of the minor systems.
- This usually occurs during more infrequent storm events, such as the 25-,50- & 100-year storms.
- The major system is composed of pathways that are provided – knowingly or unknowingly for the runoff to flow to the natural or manmade receiving channels such as: streams, creeks, or rivers.

Cont…

Fig 2.14 (a) and (b) large canals (i.e., typical examples of major storm drainage systems)

Cont…

(C). Canal with a bridge

(d). canal without bridge

2.3 Hydraulics of Urban Drainage Systems

- Hydraulic design of storm drainages systems requires an understanding of basic hydrologic and hydraulic concepts and principles.
- Hydrologic concepts will be discussed in the next chapter.
- Important hydraulic principles include flow classification, conservation of mass, conservation of momentum, and conservation of energy.
- In this section we will introduce some of these elements in the sense

of formulating the nature, considerations and approaches to the urban drainage system planning and design

2.3.1 Review of open channel flow

- The flow of water in the urban system (including flow in the settlement facilities, and flows in natural and artificial drainages/or channels/can be either open-channel flow or pipe flow, the two kinds of flow are similar in many ways but differ in one important respect.
- Open-channel flow must have a free surface, where pipe flow has none since the water must fill the whole conduit a free surface is subject to atmospheric pressure.
- In pipe flow, in which the flow being confined in close conduit, it exerts no direct atmospheric pressure but hydraulic pressure only.

Cont…

- Although closed conduits such as culverts and storm drains are open channels when flowing partially full, the term is generally applied to natural and improved watercourses, gutters, ditches, and channels.
- The design and/or analysis of roadside and median channels follow the basic principles of open channel flow.
- summaries several important open channel flow concepts and relationships are presented in the following sections.

2.3.2 Fundamental Hydraulic flow equations

- The design of drainage structures requires the use of

1) Continuity equation
2) Energy and equation
3) Momentum equation

- From these fundamental equations other equations are derived by a

combination of mathematics, laboratory experiments and field studies,

- these equations are used differently to analyze open-channel flow closed conduits flowing full.

1) Continuity equation

- The continuity equation is based on the conservation of mass
- For steady flow of incompressible fluids it is:

$$V_1A_1 = V_2A_2 = Q = VA$$

Where:

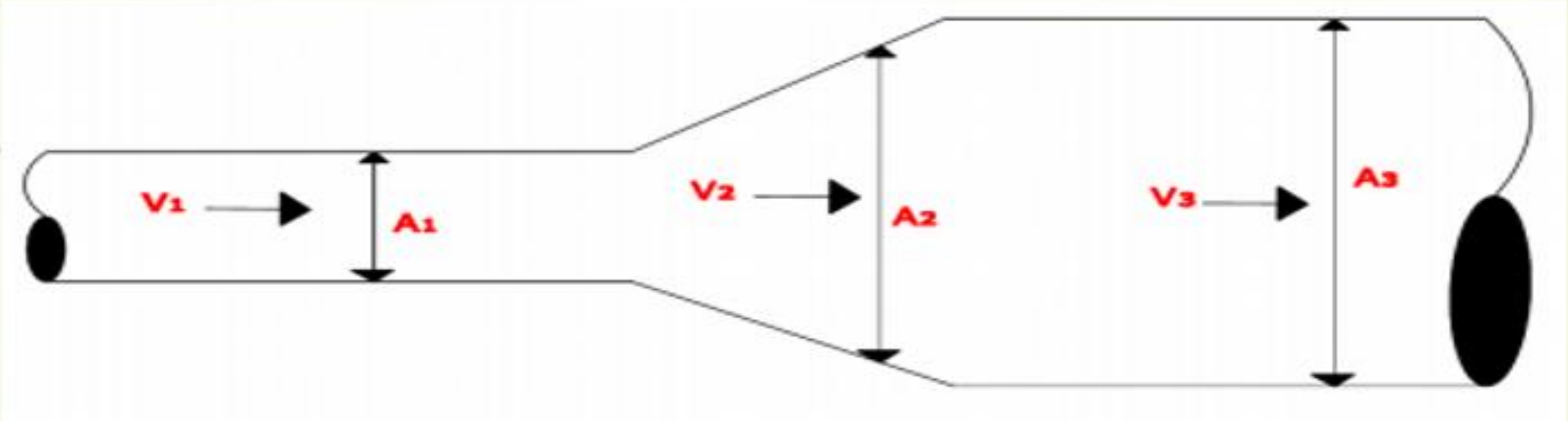
- V= average velocity in the cross section perpendicular to the area in m/s

A= area perpendicular to the velocity m^2

Q= volume flow rate or discharge, m^3/s

Cont…

- The above equation is applicable when the fluid density is constant, the flow is steady there is no significant lateral inflow or seepage and the velocity is perpendicular to the area as shown in figure below.



Example 11

1) A storm drain flowing full transitions from 0.7m to 1.0m diameter pipe. determine the average velocity in each section of pipe for a discharge 0.5m3/s.Find;

a) Velocity at section 1(0.7m pipe)

b) Velocity at section 2 (1.0m pipe)

Solution

- Since the discharge at the beginning of the pipe must equal the discharge at the end of the pipe, the continuity equation can be used.
- Basic equation: Q=VA rearranging to get V= Q/A for a circular pipe: A=(πD2)/4 , So the result will be 1.3m/s (at section 1), and 0.64m/s (at section 2).

2) Energy equation

- The energy equation is derived from the first law of thermodynamics which states that the energy must be conserved at all times. The energy equation is a scalar equation. For steady incompressible flow it is:

$$\alpha_1 \frac{V_1^2}{2g} + \frac{P_1}{\gamma} + Z_1 = \alpha_2 \frac{V_2^2}{2g} + \frac{P_2}{\gamma} + Z_2 + h_L$$

Cont…

- Where;

α = kinetic energy correction factor

V = average velocity in the cross section, m/s

g = acceleration of gravity, 9.81m/s^2

p = pressure, N/m^2

γ = unit weight of water, 9800 N/m^3 at 15 °C

Z = elevation above the horizontal datum, m

h_L = headloss due to friction and form losses, m

A = area of the cross section, m^2

- The kinetic energy correction factor α is to correct for the velocity distribution across the flow. This allows the use of the average velocity(V)rather than the point velocity(v). It is given by the following equation:

$$\alpha = \frac{1}{V^3}\int_A V^3 dA$$

Where, V=velocity at a point or average in a vertical, m/s

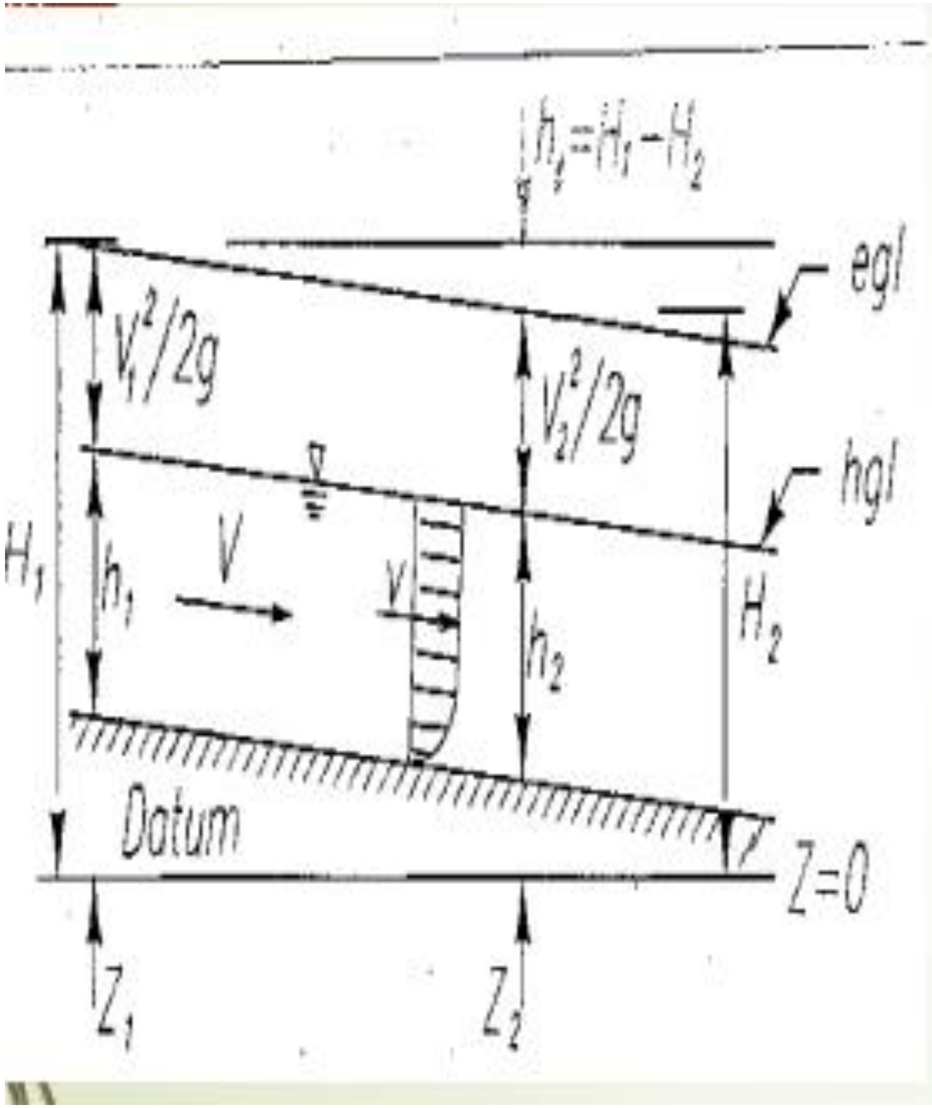
NB. Even with a very non-uniform velocity distribution across a section the correction is only 10% . Consequently the kinetic energy correction factor is normally equal to 1.0

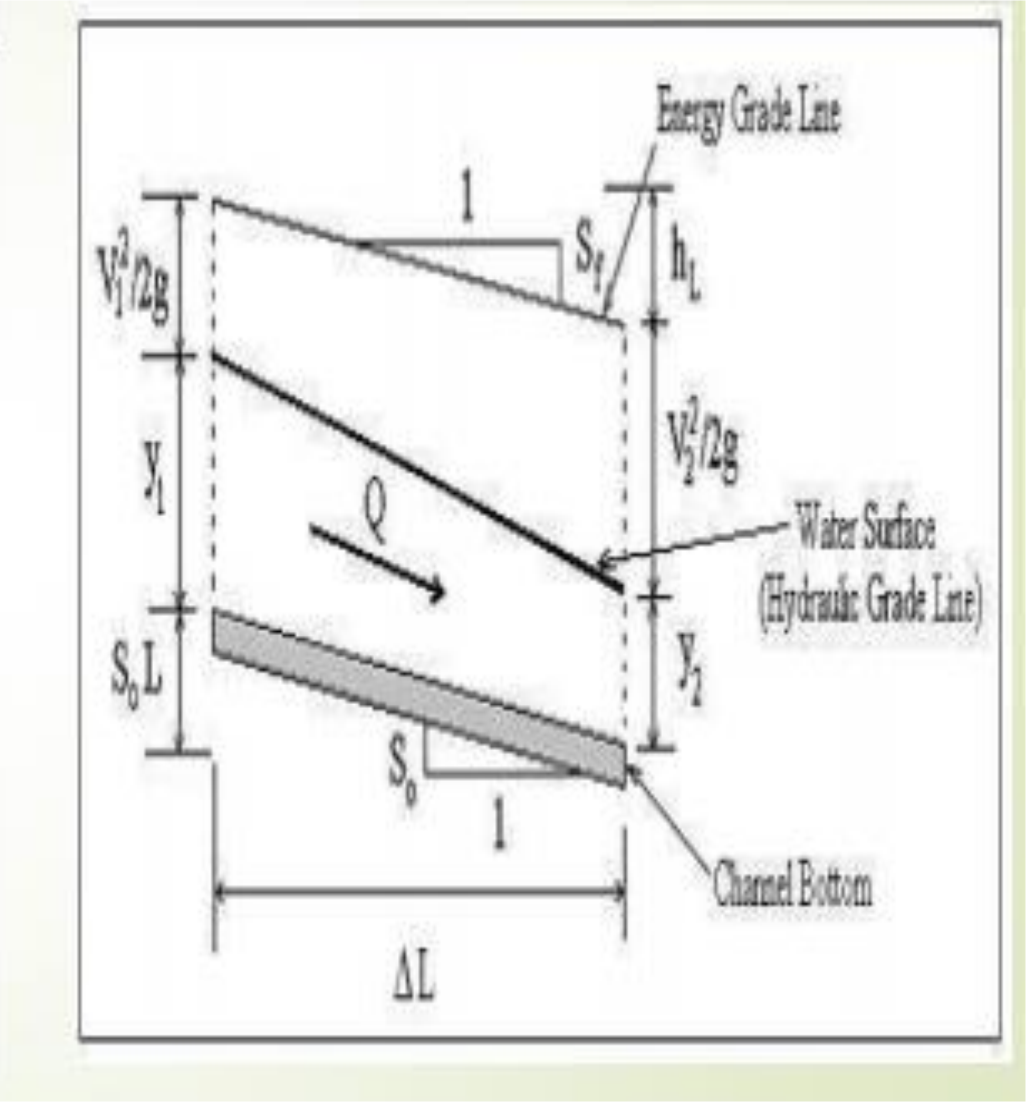
Cont…

- The energy grade line (EGL) represents the total energy at any given cross section, defined as the three components of represented on each sides of the above equation.
- These components of energy are often referred to as the velocity head, pressure head, and elevation head.
- The hydraulic grade line (HGL) is below the EGL by the amount of the velocity head, or the sum of just the pressure head and the elevation head.

Cont…

Fig 2.15 a) Sketch of energy concept for open channel flow





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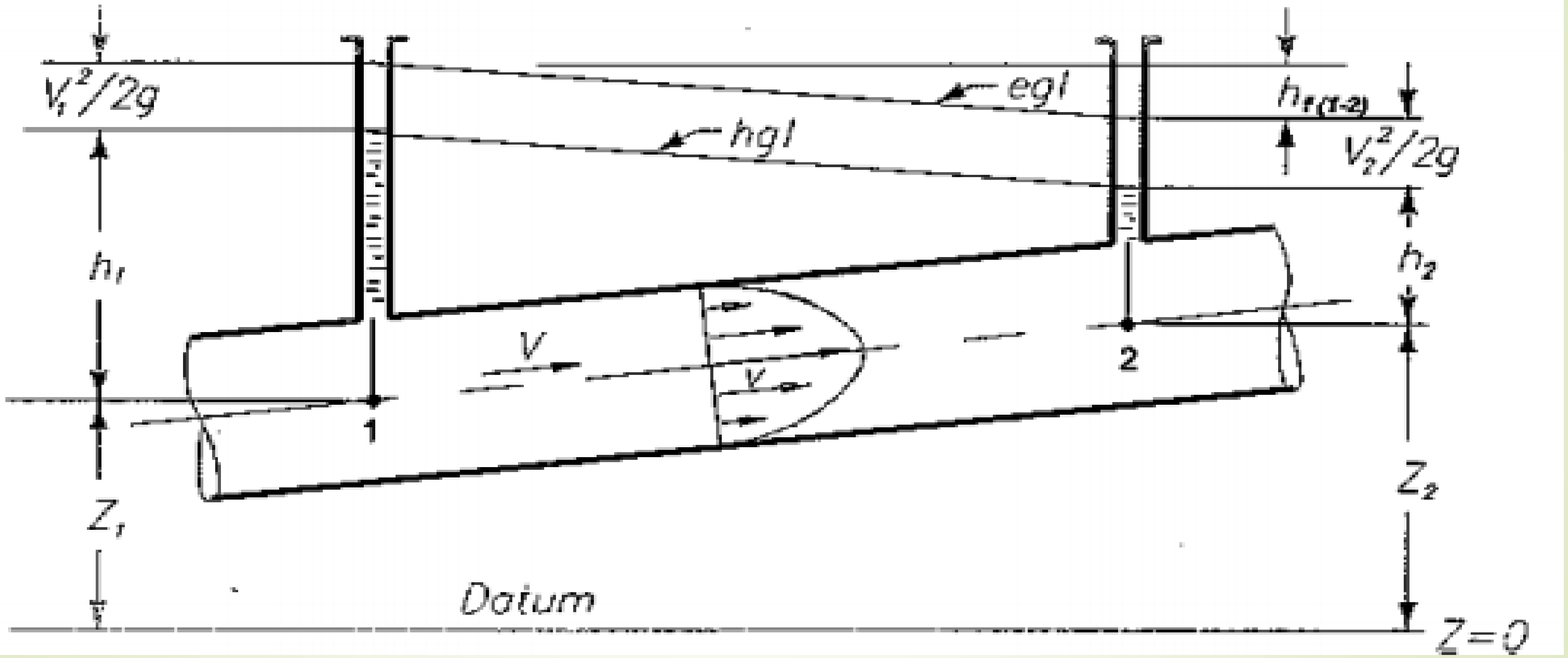
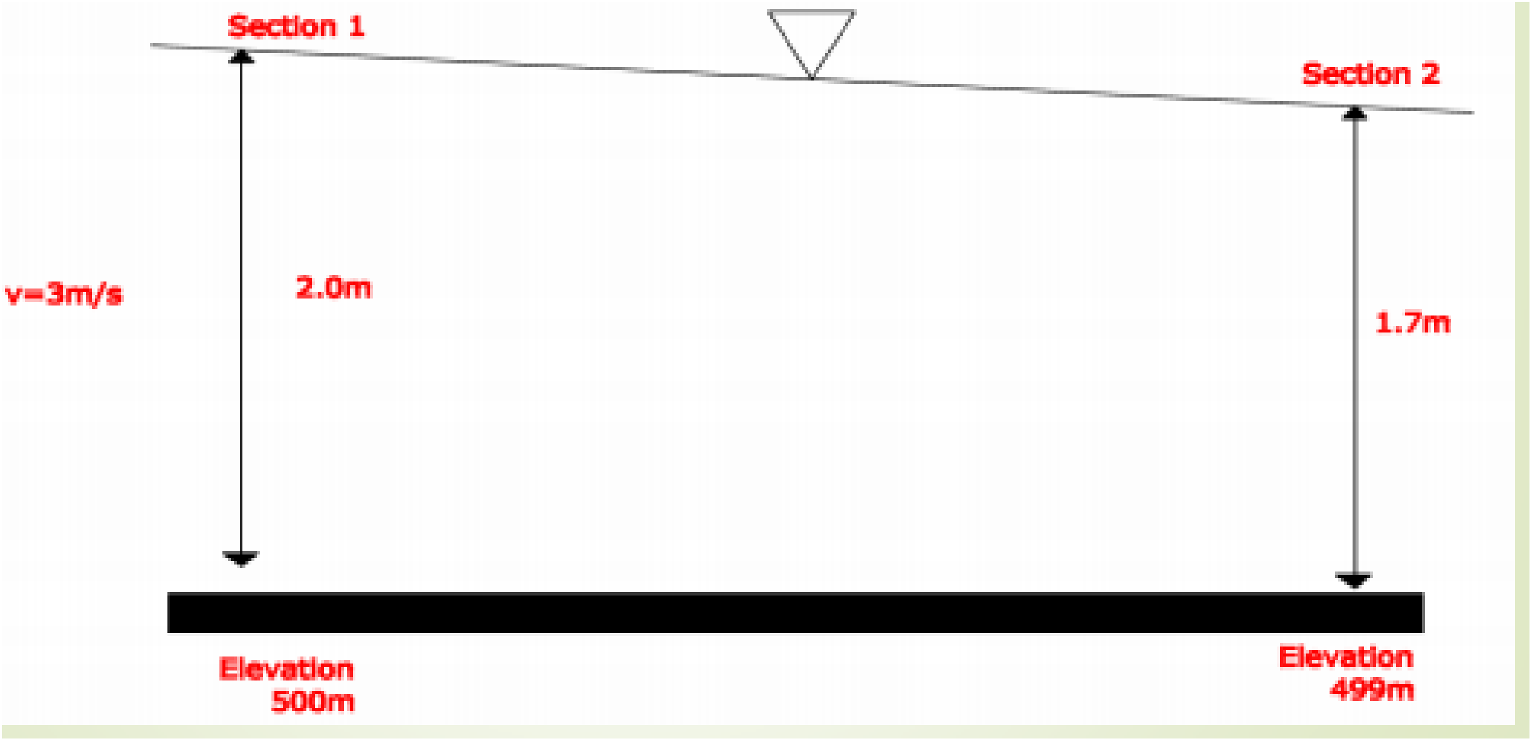
b) Sketch of energy concept for pipe flow



Example 12

- The velocity of the upstream end of a rectangular channel 1m wide is 3m/s and the flow depth is 2m. The depth at downstream end is 1.7m. The elevation at section 1 is 500m and at section 2 is 499.9m. Determine the head loss due to friction. Assume the kinetic energy correction factor is 1.0



Cont…

Solution

Step 1 use the continuity equation to find the discharge in the channel.

$Q = V_1 A_1 = 3(2)(1) = 6 m^3/s$

Step 2 use the continuity equation to find the velocity at section 2

$Q = VA$

$V_2 = Q/A_2 = (6/(1.7*1)) = 3.53 m/s$

Step 3 use the energy equation to find the head loss, h_L

- Since the flow is in open channel, $\alpha_1 \frac{V_1^2}{2g} + y_1 + Z_1 = \alpha_2 \frac{V_2^2}{2g} + y_2 + Z_2 + h_L$

$h_L = 0.23m$

3. Momentum equation

- The momentum equation is derived from Newton's 2nd law which states that the summation of all external forces on the system is equal to the change in momentum. In the x-direction for steady flow with constant density it is:

$$\sum F_X = \rho Q(\beta_2 V_{X2} - \beta_1 V_{X1})$$

Where; F_X = forces in the 'X' direction, N.

ρ = density 1000 kg/m3

β = momentum coefficient

Q = volume flow rate or discharge

V = velocity in the 'X' direction, m/s

Cont…

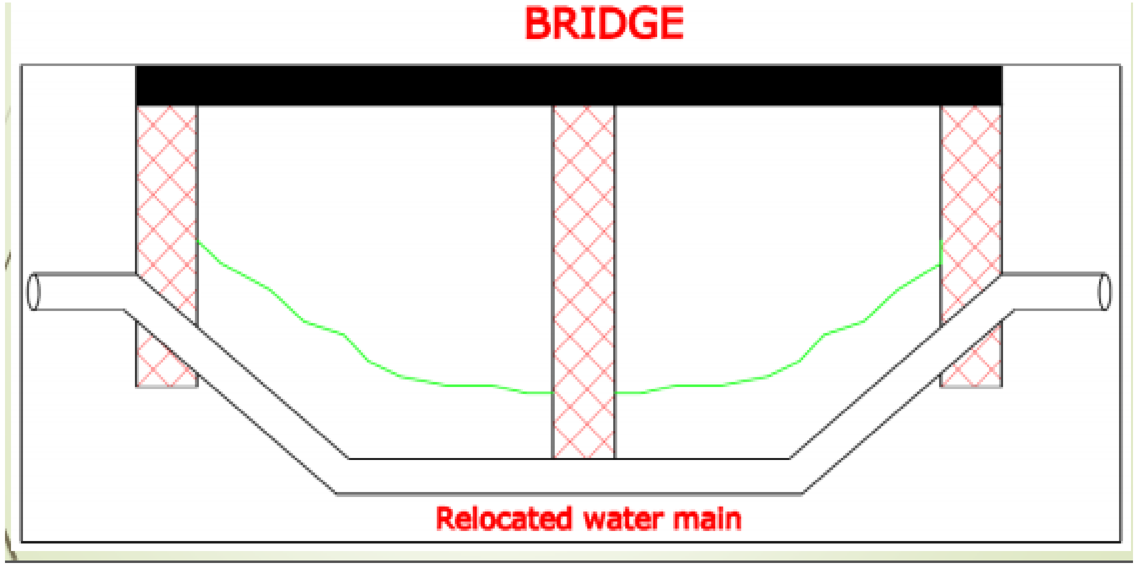
- The momentum coefficient corrects for the velocity distribution across the flow. Again this allows the use of the average velocity(V) rather than the point velocity(v). It is given by:

$$\beta = \frac{1}{V^2} \int V^2 \, dA$$

- The momentum coefficient is normally assumed to be 1.0 since a very non uniform velocity is distribution across a section would only require a correction less than 10%.
- The momentum equation is a vector equation and similar equations are used for the ‘Y’ and ‘z’ directions.

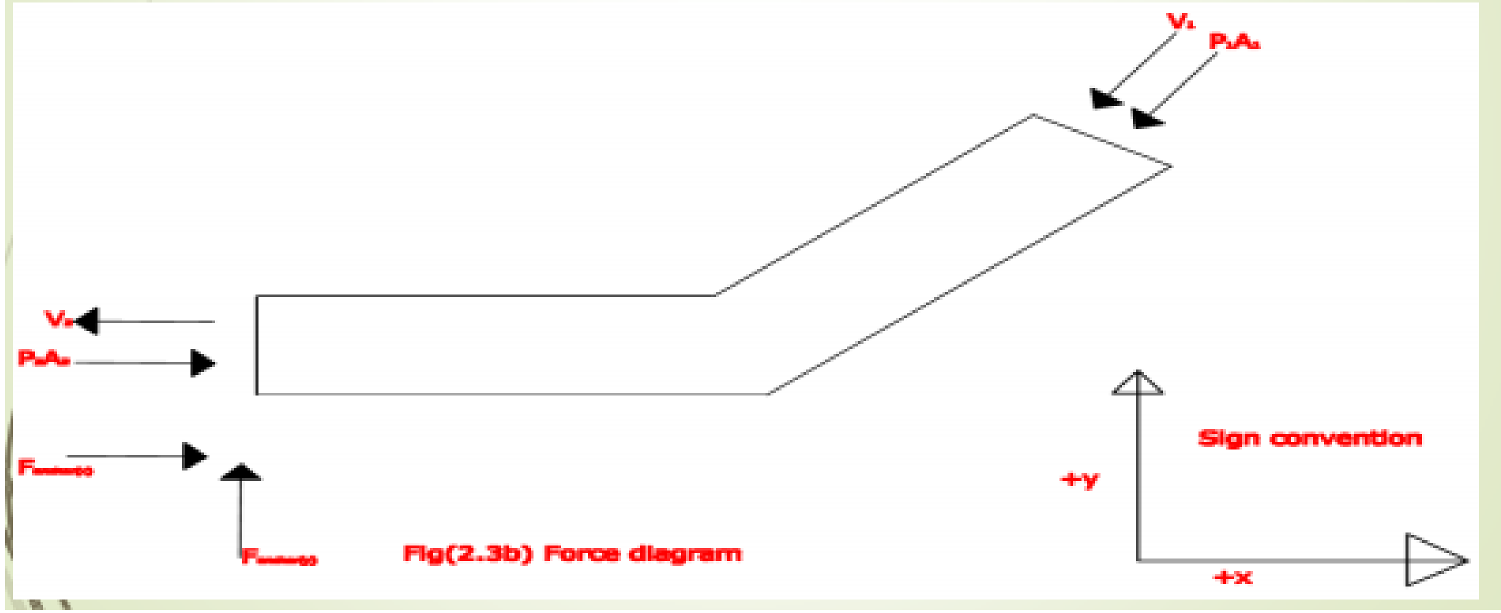
Example 13

- For a bridge widening project, an existing city water main must be relocated. The water main is 300mm in diameter and carries 0.142m3/s. Relocation of water main will require a 45 degree bend in the pipe. The pressure in the pipe at the location of the bend is 689464N/m2. determine the forces that an anchor on the pipe at the bend needs to withstand.



Solution

Velocity in pipe (result, **V=0.071m2/s)**.
(b) Use the momentum equation to find the forces on the bend in the ‘**x**’ and ‘**y**’ directions. First draw a diagram of the bend and label the forces. (note: sign convention is important in drawing a force diagram).



Fig(2.3b) Force diagram

Cont…

- The momentum equation states

$$\sum F_X = \rho Q(\beta_2 V_{X2} - \beta_1 V_{X1})$$

The force acting on the pipe include pressure on either side of the pipe and the resisting of the anchor.

$$F_{anchor\,(x)} + P_{2X}A_{2X} - P_{1X}A_{1X}\cos 45 = \rho Q(V_{2X} - V_{1X}\cos 45)$$

- First determine the forces in the 'X' direction (assuming no change in pressure through the bend):

$F_{anchor\,(x)} + (689464)(0.071)-(689464)(0.071)\cos 45 = 1000(0.142)((-2)+2\cos 45)$

$F_{anchor\,(x)} + 48952N - 34614N = - 83N$

$F_{anchor\,(x)} = \underline{-14421N}$

Cont…

- Next, determine the force in the 'y' direction:

$$\sum F_y = \rho Q(\beta_2 V_{y2} - \beta_1 V_{y1})$$

$$F_{anchor\,(y)} + P_{2y}A_{2y} - P_{1y}A_{1y}\sin 45 = \rho Q(V_{2y} - V_{1y}\sin 45)$$

$$F_{anchor\,(y)} + 0 - (689464)(0.071)\sin 45 = 1000(0.142)(0 + 2\sin 45)$$

$$F_{anchor\,(y)} - 34614N = 201N$$

$$F_{anchor\,(y)} = 34815N$$

$$F_{total} = \sqrt{(-14421)^2 + (34814)^2} = \underline{37683N}$$

F_{total} = **37683N** acting at about **113 degrees** counter clockwise from the 'X' axis. This is equivalent to the weight of two or three automobiles sitting at the top of the anchor!

4. Manning's equation

- Water flows in a sloping drainage channel because of the force of gravity. Flow is resisted by the **friction** between the **water** and **wetted surface of the channel**.
- The quantity of water flowing **(Q)** the depth of flow **(y)**, and the velocity of flow **(v)** depend upon the channel shape, roughness**(n)** and slope**(so)** .
- Various equations have been devised to determine the velocity and discharge in open channels. A useful equation is the mining's equation for the velocity of flow in open channels is:

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

Cont…

- Where:

  V= mean velocity, m/s(ft/s)

  N= manning's coefficient of channel roughness

  R= hydraulic radius, m(ft)

  S= energy slop, m/m(ft/ft),for steady uniform flow s=so

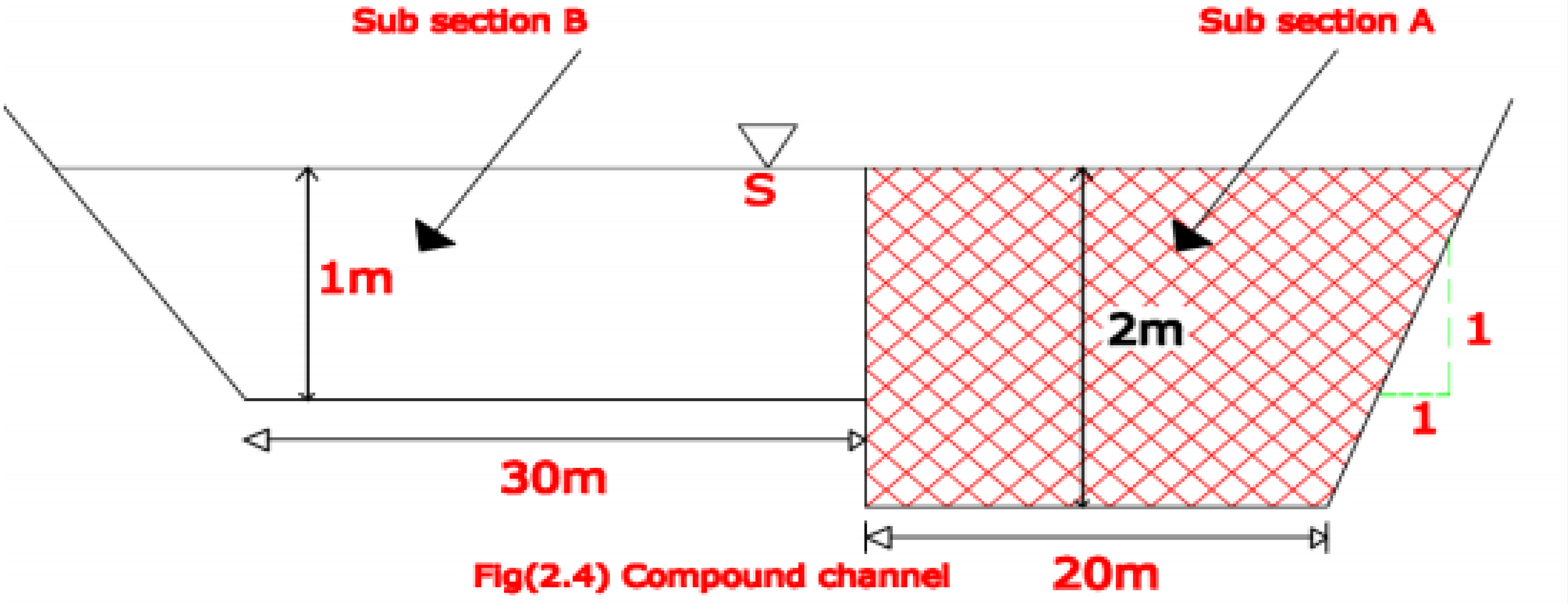
  K_u= unit conversion factor ~1(1.49 in English unit)

- Thus, $R = A/P$, and $Q = VA = \frac{K_u}{n} R^{2/3} S^{1/2} A$
- In some computation it is convenient to group the cross sectional property in to a term called conveyance, K.

$$K = \frac{K_u}{n} AR^{2/3}, \quad Q = KS^{1/2}$$

Example 14

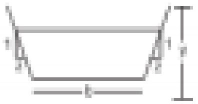
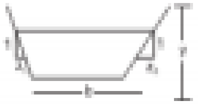
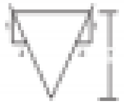
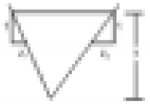
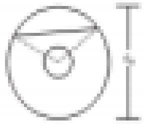
- A compound channel as illustrated below, has a roughness of **(n=0.03)** a longitudinal slop of **0.002m/m** and side slopes of **1V:1H.** Determine the total discharge of the channel.



Fig(2.4) Compound channel

Cont…

Table 2.3 Channel Section Geometric Properties

Channel definition (1)		Area A (2)	Wetted perimeter P (3)	Hydraulic radius R (4)	Top width T (5)	Hydraulic depth D (6)
Rectangle		by	$b + 2y$	$\frac{by}{b + 2y}$	b	y
Trapezoid with equal side slopes		$(b + zy)y$	$b + 2y\sqrt{1 + z^2}$	$\frac{(b + zy)y}{b + 2y\sqrt{1 + z^2}}$	$b + 2zy$	$\frac{(b + zy)y}{b + 2zy}$
Trapezoid with unequal side slopes		$by + 0.5y^2(z_1 + z_2)$	$b + y(\sqrt{1 + z_1^2} + \sqrt{1 + z_2^2})$	$\frac{by + 0.5y^2(z_1 + z_2)}{b + y(\sqrt{1 + z_1^2} + \sqrt{1 + z_2^2})}$	$b + y(z_1 + z_2)$	$\frac{by + 0.5y^2(z_1 + z_2)}{b + y(z_1 + z_2)}$
Triangle with equal side slopes		zy^2	$2y\sqrt{1 + z^2}$	$\frac{zy}{2\sqrt{1 + z^2}}$	$2zy$	$0.5y$
Triangle with unequal side slopes		$0.5y^2(z_1 + z_2)$	$y(\sqrt{1 + z_1^2} + \sqrt{1 + z_2^2})$	$\frac{0.5y^2(z_1 + z_2)}{y(\sqrt{1 + z_1^2} + \sqrt{1 + z_2^2})}$	$y(z_1 + z_2)$	$0.5y$
Circular		$\frac{1}{8}(\theta - \sin\theta)\, d_o^2$	$0.5\theta d_o$	$0.25\left(1 - \frac{\sin\theta}{\theta}\right) d_o$	$2\sqrt{y(d_o - y)}$	$\frac{1}{8}\left[\frac{\theta - \sin\theta}{\sin(0.5\theta)}\right]$

Solution

1. Sub section A

$A = 2(20) + \frac{1}{2}(2)(2) = 42m^2$

$WP = 20 + (2)(2)^{1/2} + 1 = 23.83m$

$R = 42/23.83 = 1.76m$

$V = (1/0.03)(1.76)^{2/3}(0.002)^{1/2} = 2.17m/s$

$Q = 42(2.17) =$ **$91.14m^3/s$**

2. Sub section B

$A = 30(1) + \frac{1}{2}(1)(1) = 30.5m2$

$WP = 30 + 1(2)^{1/2} = 32.41m$

$R = (30.5)/(31.41) = 0.97m$

$V = (1/0.03)(0.97)^{2/3}(0.002)^{1/2} = 1.46m/s$

$Q = 30.5\ (1.46) =$ **$44.53m^3/s$**

Cont…

3. For the entire channel

$$A = 42+30.5 = 72.5\ m^2$$

$$Q = 91.14 + 44.53 = 135.67 m^3/s \text{ say } 136 m^3/s$$

4. If the channel had been considered without subdividing, the following results would have been obtained.

$$A = 42+30.5 = 72.5\ m^2$$

$$WP = 23.83 + 31.41 = 55.23m$$

$$R = 72.5/55.23 = 1.31m$$

$$V = (1/0.03)(1.31)^{2/3}(0.002)^{1/2} = 1.78m/s$$

$$Q = 72.5(1.78) = 129.05 m^3/s$$

- This indicates the discharge obtained with out subdividing is less than the discharge obtained by sectioning the channel.
- Therefore it is preferable if entire channel is sub divided to get the relatively accurate estimate.

2.3.3 Closed Conduits Flow

- Flow conditions in a closed conduit can occur as:

1. open-channel flow
2. gravity full flow or pressure flow

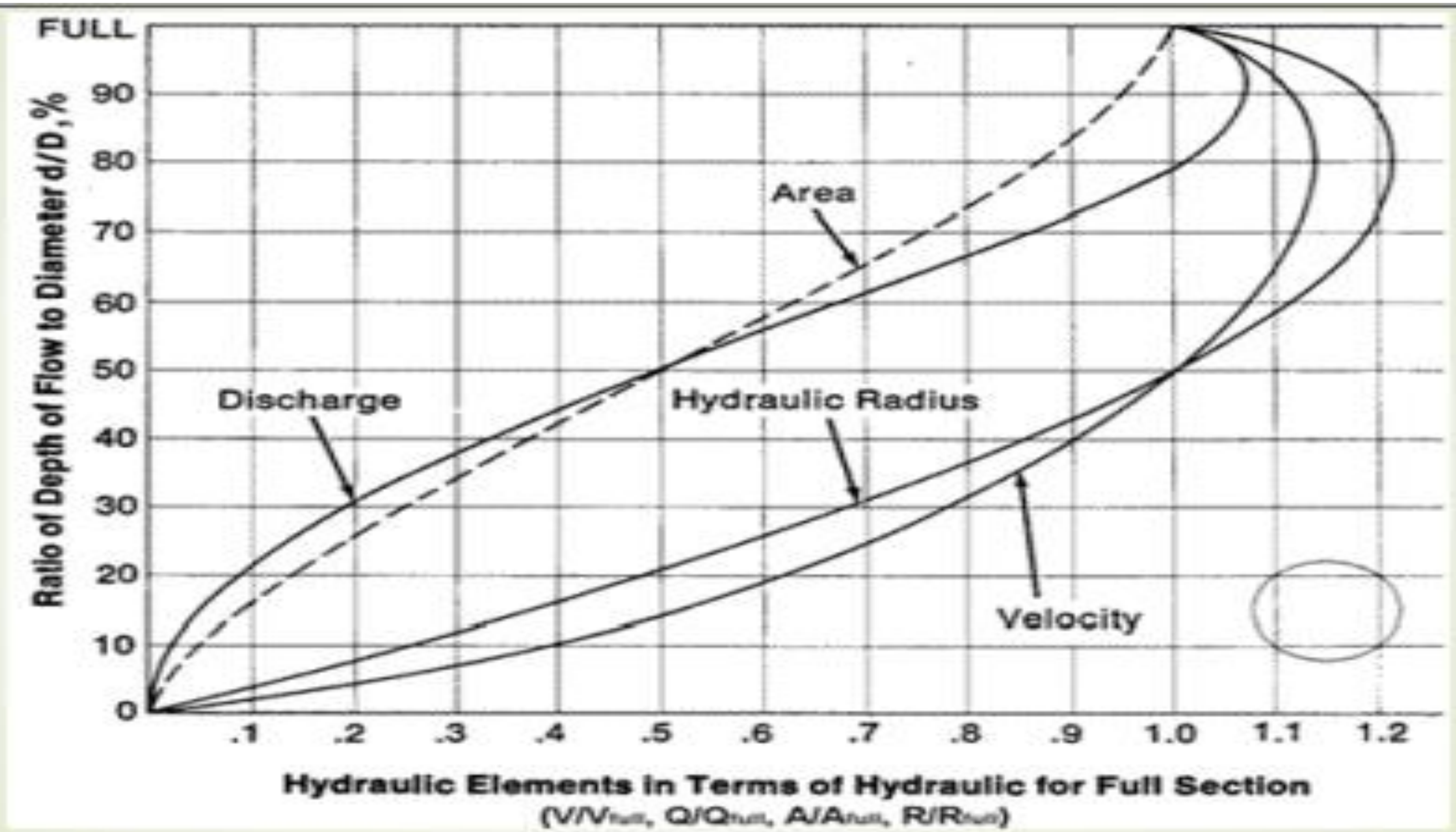
Cont…

- In open-channel flow the water surface is **exposed to the atmosphere**, which **can occur in either an open conduit or a partially full closed conduit.**
- Analysis of open-channel flow in a closed conduit is no different than any other type of open-channel flow and all the concepts and principles discussed above (in previous sections) are applicable.
- **Gravity full flow:** occurs at that condition where the conduit is flowing full but not yet under any pressure.
- Due to the additional **wetted perimeter and increased friction** that occurs in a gravity full pipe, a partially full pipe will actually carry greater flow.

Cont…

- For a **circular conduit** the peak flow occurs **at 93 percent** of the height of the pipe, and the average velocity flowing one-half full is the same as gravity full flow (As shown in Figure 2.4 below).

Cont…



Part-full flow relationships for circular pipes.

Cont…

- **Gravity full flow** condition is usually assumed for **purposes of storm drain design**.
- Manning's equation for **circular section flowing full** can be rewritten as:

$$Q = \frac{Ku}{n}(D)^{8/3}(S)^{1/2}$$

Where; Ku= 0.312(0.46)

Cont…

- This equation allows for a **direct computation of the required pipe diameter .**
- Note that the computed diameter **must be increased in size to a larger nominal dimension** in order to carry the design discharge without creating pressure flow.
- The standard SI nominal **conduit pipe sizes** are: **450, 600, 750, 900, 1050, 1200…..3600** mm of diameter.

Example 15

- Pavement runoff is collected by a series of combination inlets. During the design event the total discharge is intercepted by all inlets is **0.4m3/s** a concrete storm drain pipe (**n = 0.0013**) is to be placed on a grade parallel to the roadway grade, which is **0.005m/m**. Determine:

a) The required storm drain **pipe diameter**
b) Full flow velocity & **part full flow** velocity.

Cont…

- a) D = 0.58m or **580mm**
  b) Based on the available nominal SI conduit pipe size, the next larger nominal pipe size is **600mm**.
- Under our design conditions, a 600mm would be flowing slightly, less than the full. Based on the part full flow relation ships (fig2.4)above the velocity doent change significantly from half-full to full.
- How ever for tc calculation part-full flow velocity is used.

Cont…

- To calculate the part-full velocity, nomographs or trial and error solutions can be used. Alternately the part-full flow relationship can be used.
- Thus the full-flow discharge and velocity of 600mm concrete pipe are:

$$Q = \left(\frac{0.312}{0.013}\right)(0.6)^{8/3}(0.005)^{1/2} = \mathbf{0.43m^3/s}$$

$$V = Q/A = 0.43/\frac{\pi\,(0.6)^2}{4} = \mathbf{1.52m/s}$$

Cont…

- The ratio of part full flow discharge

  $Q/Qf = 0.4/0.43 = 0.93$

- The corresponding velocity ratio from (fig 2.4) is **1.13**
- Therefore

  V/V

  f = 1.13

  V = (1.13)* Vf = (1.13)*(1.52)

  V = 1.72m/s