“Storm Water Management & Urban Flooding and its Mitigation Strategies”

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Key Resource Persons WASH Institute

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Time: 4:00 hrs.

#Storm Water Drainage

- This session is aimed at developing methodical approach towards integrated storm water drainage system.
- Monsoon is considered as lifeline of Indian sub-continent, which becomes chaotic due to water logging.
- Systems approach could address the issue of such unprecedented inundation by carrying out detailed engineering and techno-economical analysis of design parameters of each component of storm water drainage.
- Interception of wastewater being discharged into the storm drain is other side of the coin to be addressed so that integrated solution could be developed.

Stormwater drainage system

- Existing situation and coverage of SDS system in India
- The need for Stormwater management
- Issues related to SDS (Design and O&M)
- Type of SDS
- Design parameter
- Consideration for design and implementation,
- Cost of different types of SDS (such as branch, trunk, etc)
- Planning requirement of SDS
- A case study of Vapi town

Existing situation & coverage of SDS system in India

- ❖Every town has implemented SDS in piece-meal manner
- ❖Extent of coverage ranges from 20% to 75%
- ❖Prominent efficiency is lack of integrated approach
- ❖Runoff is not governed by boundary set up by humans
- ❖e.g. Let us take a town boundary for an area located in plains. Generally towns are situated in plain areas and minuscules/ hillocks surround the town.
- ❖All of us are aware since our school days that rainfall occurs due to collision of clouds with hillocks. In present case, runoff occurring beyond boundary of town(setup by any authority) will also enter into town.
- ❖Hence, catchment area should be counted on basis of total contributing area.
- ❖Municipal engineers are restrained with in town limits, but runoff won't!!!
- ❖As a result drain size derived on basis of catchment area with in town proves to be inadequate.

Issues related to SDS (Design and O & M)

- Design of Stormwater Drainage System (SDS) face following challenges
  - DATA AVAILABILITY –
    - In order to determine design rainfall intensity, data of rainfall in a particular region is required, preferably hourly basis over 30 years. GENERALLY NOT AVAILABLE
    - Daily rainfall data interpretation with help of certain empirical equation is available. But such records are also not available over long duration. In absence of such data, minimum 5 years data record is used to arrive at conclusion on rainfall intensity.
    - Catchment studies for selected region and demarcation of contributary area
    - Flood pattern over last 50 years
  - CHANGING PATTERN OF DRAINAGE–
    - Since roads are constructed on old layers, topography of town changes and every time one identifies new area being inundated.
    - Instead of waterlogging on roads, now houses undergo submergence

Issues related to SDS (Design and O & M)

- UTILITY MAPS –
  - In order to determine location of SDS on a particular road, there exists
    - ✓ Water supply pipeline
    - ✓ Underground sewerage pipeline
    - ✓ Telephone cables
    - ✓ Gas pipeline
    - ✓ Other minor utilities
- RECEIVING BODY DETAILS –
    - ✓ Since stormwater collected needs to be discharged into natural drain, it's HFL, carrying capacity must be determined on basis of past records

GENERALLY NONE OF THE DATA IS AVAILABLE

Planning of SDS (Design and O&M),

- Identification and marking of probable drainage zones, direction of gradients and selection of disposal points (based on detailed contour survey)
- Preparation of topographical layout of collection and conveyance.
- Identification of locations for discharge of stormwater or pumping stations
- Strategy for rainwater storage and its recharge to ground water
- Strategy for prevention of solid waste into storm water ways.
- Strategy for arresting pollutants with urban runoff from entering into water bodies
- Conserving the aesthetic, public safety and other social concerns of recreational open space and landscape to preserve the ecological nature ofwater ways;
- Identification of existing storm water drains / drainage corridors including age-old drainage conduits for rehabilitation;
- Non-structural measures should be studied and components designed accordingly to provide relief during occurrence of disasters due to flooding.
- Frame a Road Map for Urban Storm Water Best Management Practices (BMP).

Planning of SDS (Design and O&M),

- Preparation of strategy for protection of urban areas from flooding
- Strategy for sustainable operation & maintenance of storm water systems
- Holistic approach to local area planning including aspects of sustainability, consistency and responsive to community values.

Data collection

1. Physical characteristics
2. Rainfall characteristics
3. Waterway characteristics
4. Topographical survey and contour

Type of SDS (Design and O&M),

❑ TYPE OF DRAIN TO BE SELECTED-

- ❖ In order to select circular or rectangular, have general ideology to keep pipe drain for street upto 7.5 m and beyond rectangular drain should be preferable.
- ❖ Rectangular drain permits gentle slope as compared to pipe drain
  - Basic hydraulic principles like Brownian motion has considerable effect on the friction offered to flow by closed conduit.
  - It is also observed that whenever divided carriageway exists, one side of the road is having more water logging. In such case, modifying the divider design in zig-zag pattern could help spread of water, thus depth of water logging is restricted.

Design steps

Design Flow calculation

- Step1: Obtain historical rainfall data of 30 years or more

- Continuous series of daily rainfall data of self recording rain gauges (SRRG) are required or successive 15 minute interval rainfall data are required. But actually, we get daily rainfall data only.

- Step 2: Select return period

SR no.	Urban Catchment	Return period	
		Class 1 city	Class 2 city
1	Central Business and Commercial	Once in 5 year	Once in 2 year
2	Industrial	Once in 5 year	Once in 2 year
3	Urban residential	Once in 5 year	Once in 2 year
4	Airports, power stations	Once in 100 year	Once in 50 year

Note: Class 1 cities have population more than 1 lakh; less than it forms class 2 cities

Design steps

Design Flow calculation

❑ Step 3 : Preparation of IDF curve

Intensity-Duration-Frequency curves

- IDF curves shows relation of rainfall intensity and duration of rain storm for a particular frequency also known as return period.
- For design of storm water system, design rainfall intensity is the intensity corresponding to time of concentration of given project area.
- According to topography of project area, it is divided in certain catchment pockets having single outlet point.
- These points connect to form storm water drains.
- Time of concentration is the maximum time water can take to reach design outlet point from any point in catchment pocket.
- Rainfall Intensity corresponding to the maximum time of concentration among all catchment pockets is considered as design rainfall intensity

Design steps

Design Flow calculation

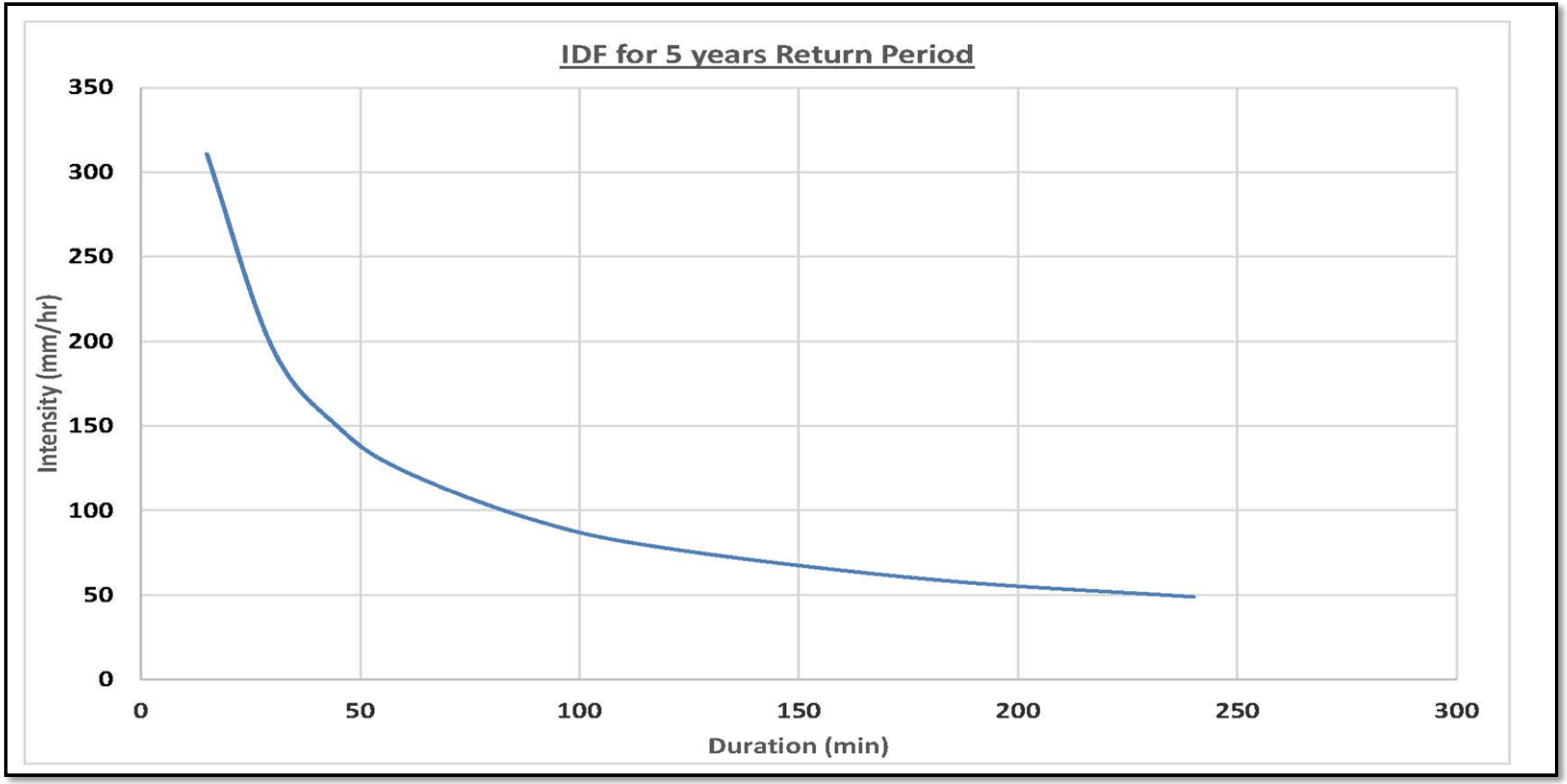
Deriving Intensity-Duration-Frequency curves

- Required data: minimum 30 years of annual maximum data series for storm duration of 1-hour,2 hour,4 hour,6 hour, 12 hour,24 hour.
- In reality we have only 24 hour cumulative rainfall data, which needs to be converted in maximum rainfall data for above mentioned storm durations
- Formula given by IMD or formula given by IRC-42 is used for this conversion
- Next step is fitting these maximum event data in suitable probability distribution for obtaning intensity v/s duration curve.

Design steps

Design Flow calculation

Deriving Intensity-Duration-Frequency curves



Design steps

Design Flow calculation

Deriving Intensity-Duration-Frequency curves

❖ The various probability distribution functions are listed below

Distribution	PDF	Range	Equations for parameters in terms of sample moments
Gumbel's Extreme Value – I	$f(x) = \frac{1}{\alpha} exp\left\{-\frac{x-u}{\alpha} - exp\left(-\frac{x-u}{\alpha}\right)\right\}$	$-\infty < x < \infty$	$\alpha = \frac{\sqrt{6}s_x}{\pi}$ $u = \bar{x} - 0.5772\alpha$
Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left\{-\frac{(x-\mu)^2}{2\sigma^2}\right\}$	$-\infty \leq x \leq \infty$	$\mu = \bar{x}$ $\sigma = s_x$
Lognormal	$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} exp\left\{-\frac{(y-\mu_y)^2}{2\sigma_y^2}\right\}$ where, $y = \log x$	$x > 0$	$\mu_y = \bar{y}$ $\sigma_y = s_y$
Exponential	$f(x) = \lambda e^{-\lambda x}$	$x \geq 0$	$\lambda = \frac{1}{x}$

Reference: Chow et al. (1988), Applied Hydrology, Tata-McGraw Hill Publications, New Delhi, pp. 372-373.

Design steps

Design Flow calculation

Deriving Intensity-Duration-Frequency curves

Distribution	PDF	Range	Equations for parameters in terms of sample moments
Gamma	$f(x) = \frac{\lambda^\beta x^{\beta-1} e^{-\lambda x}}{\Gamma(\beta)}$ where, Γ = gamma function	$x \geq 0$	$\lambda = \frac{\bar{x}}{s_x^2}$ $\beta = \frac{\bar{x}^2}{s_x^2} = \frac{1}{CV^2}$
Pearson Type III (three parameter gamma)	$f(x) = \frac{\lambda^\beta (x-\epsilon)^{\beta-1} e^{-\lambda(x-\epsilon)}}{\Gamma(\beta)}$	$x \geq \epsilon$	$\lambda = \frac{s_x}{\sqrt{\beta}}$, $\beta = \left(\frac{2}{C_s}\right)^2$ $\epsilon = \bar{x} - s_x\sqrt{\beta}$
Log Pearson Type III	$f(x) = \frac{\lambda^\beta (y-\epsilon)^{\beta-1} e^{-\lambda(y-\epsilon)}}{x\Gamma(\beta)}$ where, $y = \log x$	$\log x \geq \epsilon$	$\lambda = \frac{s_y}{\sqrt{\beta}}$, $\beta = \left[\frac{2}{C_s(y)}\right]^2$ $\epsilon = \bar{y} - s_y\sqrt{\beta}$

Reference: Chow et al. (1988), Applied Hydrology, Tata-McGraw Hill Publications, New Delhi, pp. 372-373.

Design steps

Design Flow calculation

Deriving Intensity-Duration-Frequency curves

❖ For Indian meteorology, Gumbel's extreme value distribution is most suitable

$$X_T = u + \alpha\, y_T \qquad (3.2)$$

Where, u and α are the mode of distribution and sample moments respectively which is given by the following equation.

$$u = \overline{X} - 0.5772\alpha \qquad (3.3)$$

$$\alpha = (\sqrt{6} / \pi) S_x \qquad (3.4)$$

A reduced variate y_T for a return period can be defined as

$$y_T = -ln\left[ln\left(\frac{T}{T-1}\right)\right] \qquad (3.5)$$

Where,

X_T = T- year return period value

$\bar{X}$ = Mean of the N observations

S_x = Standard deviation of N observations = $\sqrt{\frac{(x-\bar{x})^2}{N-1}}$

X = Rainfall Event

T = Recurrence interval (Storm Return Period)

N = Sample size

Note: Reference; storm water manual, CPHEEO ,vol. I , page 46

Example IDF of Vapi nagarpalika is shown in the next slide

Design steps

Design Flow calculation

- ❑ Step 4 : Demarcate the catchment
- ❖ Demarcate the catchment boundary considering area contributing to total run off at project site.
- ❖ Also mark catchment pockets with in project area
- ❑ Step 5: Determine the time of concentration (tc)
- ❖ As discussed earlier, the time of concentration (tc) is defined as flow travel time taken from the hydraulically most remote point in the contributory catchment to the point under consideration.
- ❖ Typically, this time consists of two components:
- ❖ i. Time for the surface flow to reach the first inlet, i.e., t_0
- ❖ ii. Time to flow through the storm drainage system to the point of consideration i.e. t_f
- ❖ $t_c = t_0 + t_f$

Design steps

Design Flow calculation

Following points are to be considered while calculating time of concentration

- ❖ The inlet time is dependent on the distance of a farthest point in the drainage catchment to the inlet manhole as well as, on the shape, characteristics and topography of the catchment.
- ❖ It generally varies from 5 to 30 minutes in urban areas
- ❖ In hilly areas the inlet time may be as low as 3 minutes, where steep slopes are encountered

Design steps

Design Flow calculation

i) Time of surface flow, t_0

- This formula is derived by Corps of Engineers, USA

$$t_o = \frac{0.994\,(1.1-C)L^{0.5}}{S^{0.333}} \qquad (4.4)$$

Where,

t_o : Time of surface flow (Minutes)

C : Rational Method runoff coefficient

L : Length of surface flow (m)

S : Surface Slope, in percentage (%)

Note: If slope (S) is expressed as a ratio, then the formula to be applied is

Note: Reference; storm water manual, CPHEEO ,vol. I , page 54

Design steps

Design Flow calculation

ii) Time of flow, t_f

$$t_f = \frac{L_{drain}}{V} \tag{4.6}$$

The velocity of flow in m/s is computed from the Manning's equation

$$V = \frac{1}{n} R^{0.67} S^{0.5} \tag{4.7}$$

Where,

V : Velocity of Flow, m/sec

t_f : Time of travel, minutes

n : Manning's roughness coefficient

R : Hydraulic radius, m

S : Longitudinal slope

Note: Reference; storm water manual, CPHEEO ,vol. I , page 54

Design steps

Design Flow calculation

- ❑ Step 6: Determine rainfall intensity against the time of concentration from IDF curve
- ❑ Step 7: Determine runoff coefficient (C)
- ❖ The coefficient of runoff (C), is a function of the nature of surface and assumed to be the same for all storms of all recurrence probabilities.
- ❖ Recommended values of C on various surface types of the catchments are given in Table
- ❖ While choosing the values for C, the ultimate development of the catchment as per the master plan should be taken into consideration.
- ❖ Weighted average runoff coefficient of catchment area containing different character of surfaces for a flow concentrating at a point is estimated to get runoff coefficient for entire project area.

Design steps

Design Flow calculation

S. No.	Type of Area	Runoff Coefficient
1	Commercial Area	0.70 – 0.95
2	Industrial Area	0.60 – 0.90
3	Institutional Area	0.70 – 0.95
4	Residential Area -High Density -Low Density	0.60 - 0.75 0.40 - 0.60
5	Recreational areas	0.10 - 0.25
6	Pavement - Asphaltic Pavement - Concrete Pavement - Brick Pavement	0.70 - 0.95 0.80 – 0.95 0.70 - 0.85
7	Roof Catchment - Tiles - Corrugated metal sheets - Concrete	 0.8-0.9 0.7-0.9 0.7-0.90

Source: Adapted from ASCE and WPCF 1969

Design steps

Design Flow calculation

- Step 8: Calculate peak flow by Rational formula

Assumptions of rational formula

- The maximum size of a catchment should be between 8 to 10 sq km
- Larger catchments can be sub-divided into smaller sub-catchments
- The peak flow occurs when the entire catchment is contributing to the flow
- The rainfall intensity is uniform over the entire catchment
- The rainfall intensity is uniform over a time duration equal to the time of concentration
- The frequency of the computed peak flow is the same as that of the rainfall intensity corresponding to the return period of the 'design storm.'
- The coefficient of runoff is the same for all storms of all recurrence probabilities

Design steps

Design Flow calculation

The formula for calculating peak flow is given as below:

- $Q_p = 10\ C\ I\ A$
- Where,

  Q_p : Peak flow at the point of design, m3/hr

  C : Runoff coefficient, dimensionless

  I : Design Average rainfall intensity in mm/hr

  A : Catchment area, hectares

- If properly understood and applied, rational method can produce satisfactory results for sizing storm drains, street inlets, and small on-site detention catchments.

Design steps

Hydraulic Design of storm drain

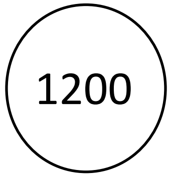
- The flow in storm design is categorized as open channel flow
- For design purpose, it is assumed that flow is in steady turbulent conditions either uniform, non-uniform gradually or rapidly varied flow.
- Majorly, there area two types of storm drains: box drain and circular drain.
- For roads more than 7 m wide, box drain are preferred, while for smaller roads pipe conduits are preferable.

Design steps

Hydraulic Design of storm drain

Hydraulic efficiency of box drain and circular drain

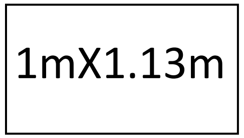
For example, take a pipe of diameter 1200 mm. The cross section area will be 1.13 sq.m.



The slope is 1 in 500

On applying Manning’s formula (as demonstrated in next slide) for flow calculation, the flow value is 2020 lps.

For same cross section area, dimension of box drain will be 1 m deep and 1.13 m wide



The slope is 1 in 500

On applying Manning’s formula (as demonstrated in next slide) for flow calculation, the flow value is 2343 lps.

Thus, for same cross section area, the carrying capacity of box drain is 16% higher than that of circular section. Hence, hydraulic efficiency of box drain is higher than that of circular drain.

Design steps

Hydraulic Design of storm drain

Design consideration

- The width is as per the local width available for the construction of the drains
- Depth should be estimated based on Manning's formula

$$Q = (1/n) \times (A^{5/3}/P^{2/3}) \times S^{1/2}$$

Where,
S = Hydraulic slope in m/m; n = Manning's coefficient of roughness
P= wetted perimeter in m; A= Area of cross section of water area in m2
Q= Discharge in m3/sec

- As far as possible rectangular drains should be provided as the are more hydraulically efficient
- Economical section is b=2d
- As per IRC 50: Minimum width of drain should not be less than 250 mm and incase of pipe the minimum diameter should not be less than 450 mm.

Design steps

Hydraulic Design of storm drain

Design consideration

- To ensure that deposition of suspended solids does not take place, velocity should be maintained between 0.6 m/s to 3 m/s.
- The freeboard is the vertical distance from the water surface of designed flow condition to the top of the channel
- Freeboard should be sufficient to prevent waves, super elevation changes, or fluctuations in water surface from overflowing the sides. Recommended free board is as given below

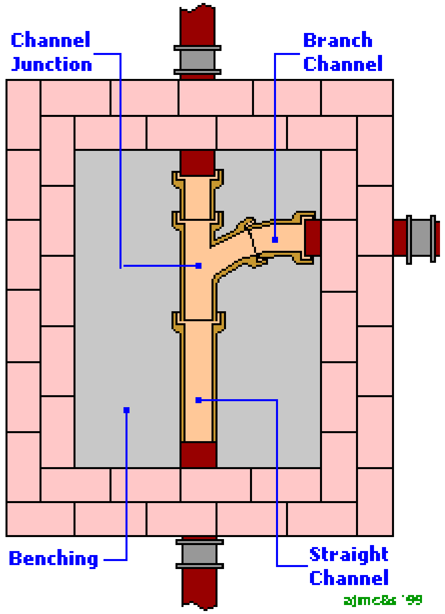
	Drain Size	Free Board
(i)	Beyond 300 mm bed width	10 cm
(ii)	Beyond 300 mm & up to 900 mm bed width	15 cm
(iii)	Beyond 900 mm & up to 1500 mm bed width	30 cm

Design steps

Hydraulic Design of storm drain

Design consideration

- Due to unavoidable curves and bends, erosion takes place along the drain surface, a minimum radius of curvature of 3 times the width of the drain should be provided in horizontal curve. Benching should be provided at the bend to minimize the sedimentation at the inner side of the bend.
- A sump of sufficient size shall be provided where drains converge or intersect.
- The minimum internal width of the sump shall not be less than 2 times the width of the drain leading away from the sump.
- Generally slope should not be less than 0.3%, But in flat terrain it can go upto 0.2%



Design steps

Hydraulic Design of storm drain

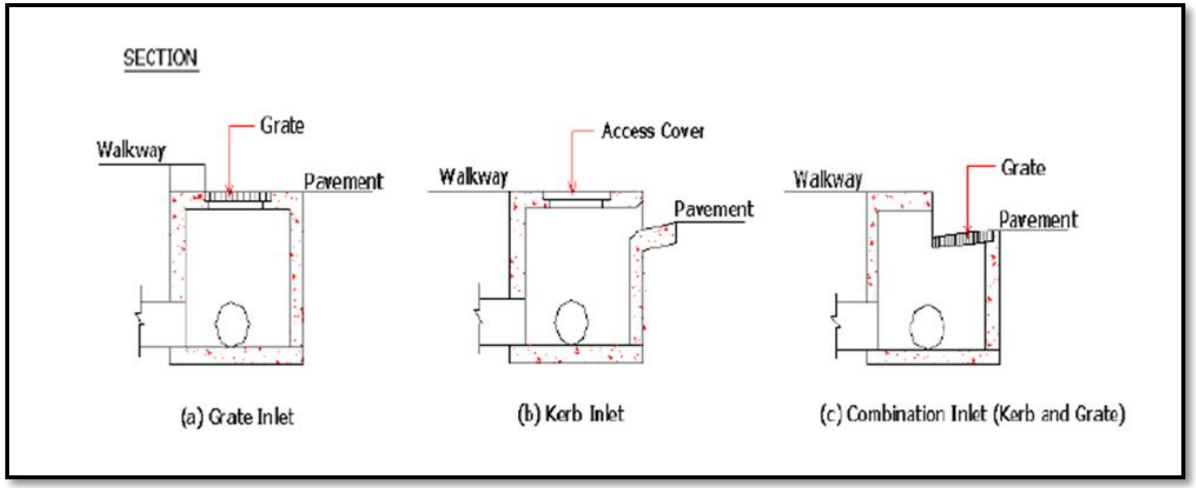
Design consideration

- Storm water inlets are devices used to collect runoff and discharge it to an underground storm drainage system.
- Inlets are suitably located on pavements, in gutter sections, paved medians, road side and at locations of specific requirement
- There are three type of inlets: kerb inlets, grate inlets, combined inlets

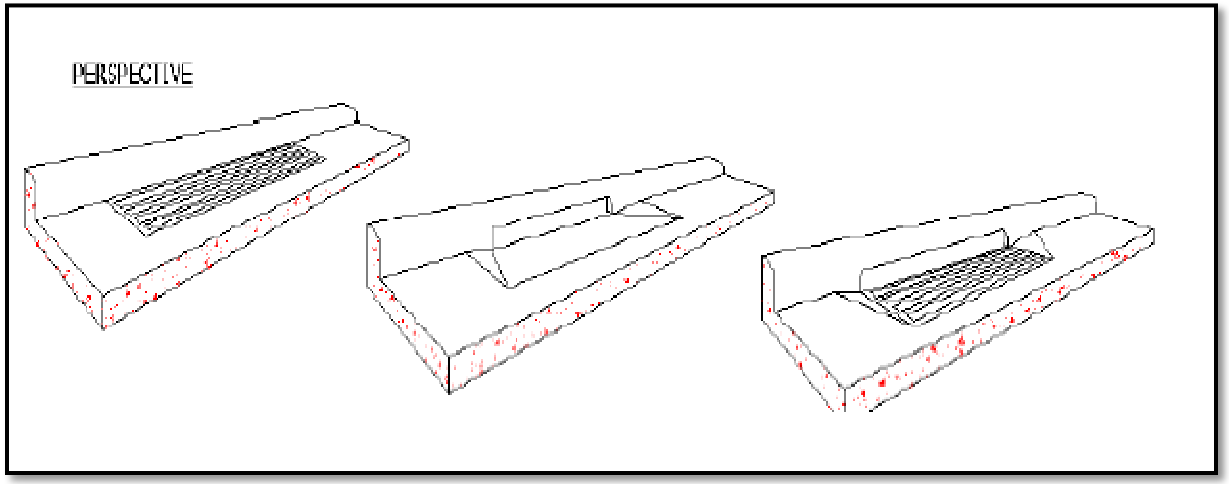
Design steps

Hydraulic Design of storm drain

Design consideration



Cross section of inlet



Plan section of inlet

Design steps

Hydraulic Design of storm drain

Design consideration

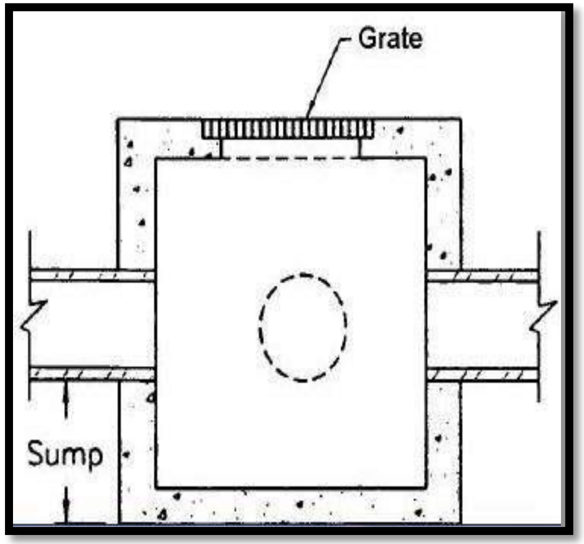
- ❖ If the Inverted Level(IL) of the drain is lower than the MWL in natural drain then natural drainage water starts entering into the storm water drains
- ❖ In this case slope has to be modified and designed such that the IL of storm water drain is higher than MWL of natural drain.
- ❖ If the outlet of storm water drain is at creek (shallow depth stream, generally near sea), IL of storm water drain should be higher than high tide level, else sea water will enter the drain.

Design steps

Hydraulic Design of storm drain

Design consideration

- The catch basin illustrated in Figure is a special type of inlet structure designed to retain sediment and debris transported by storm water which might enter into storm water system and clog the storm pipes.
- A separate catch basin may be used for each street inlet or to save expenses, the pipes from several outlets at a corner may discharge into the same catch basin
- Catch basin sumps require periodic cleaning to be effective and if not properly maintained they may become odorous and mosquito nuisance.



Design steps

Hydraulic Design of storm drain

Design consideration

Flow variation when circular section is partially filled

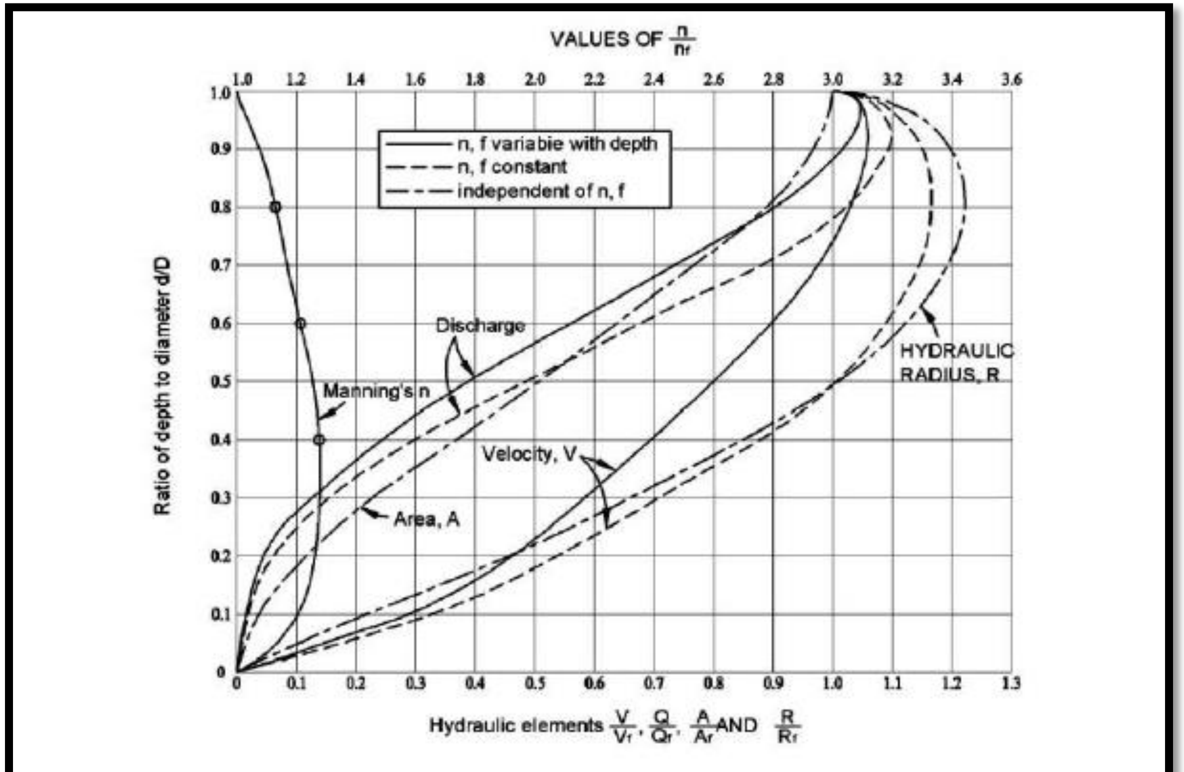
- ❖ When the flow in storm water drain is inadequate, and flow is q, the variation in hydraulic radius, depth and velocity can be derived from charts.
- ❖ Considering flow, velocity, depth and hydraulic radius at full flow condition as Q, V, D, R and the same in partial flow case as q, v, d, r respectively
- ❖ Ratios are calculated as d/D, v/V, d/D, r/R and correction factors for each parameter is obtained from chart or table derived from chart.

Design steps

Hydraulic Design of storm drain

Design consideration

Flow variation when circular section is partially filled



	Constant (n)			Variable (n)	
d/D	v/V	q/Q	n_o/n	v/V	q/Q
1.0	1.000	1.000	1.00	1.000	1.000
0.9	1.124	1.066	1.07	1.056	1.020
0.8	1.140	0.968	1.14	1.003	0.890
0.7	1.120	0.838	1.18	0.952	0.712
0.6	1.072	0.671	1.21	0.890	0.557
0.5	1.000	0.500	1.24	0.810	0.405
0.4	0.902	0.337	1.27	0.713	0.266
0.3	0.776	0.196	1.28	0.605	0.153
0.2	0.615	0.088	1.27	0.486	0.070
0.1	0.401	0.021	1.22	0.329	0.017

Thank you

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