Guidelines for design of small bridges & culverts (IRC:SP:13-2020)

Design of CD Structure (Location, Size, Type, and other details) should cater to the requirements of Discharge and Balancing of water levels on either side of Embankment

Culvert: It is a cross drainage structure having a total length of 6.0 M or less between the interface of dirt walls or extreme vent way boundaries.

Note: Cross Drainage Structures with pipes will be termed as Culverts irrespective of length

Small Bridge: It is a cross drainage structure having a total length from 6.0-30.0 M between the interface of dirt walls or extreme vent way boundaries.

Site Selection

Preferable:

- Straight reach of the stream, sufficiently downstream of bends
- Straight Reach of the road
- Well defined banks
- Square Crossings

Design Data Collection

A. Location of structure
    a. D = Distance from Sea Coast in km
B. Catchment Area
    a. M = Catchment Area in Sq.km/Ha (depending on the formula used)
    b. L = Distance from farthest (critical) point on catchment area to structure in km
    c. H = Fall from farthest (critical) point on catchment area to structure in m
C. Cross Sections
D. Longitudinal Section Note1
E. HFL Markings
F. Velocity Observations
G. Trail Pit Section
    a. Scour depth
    b. Silt factor
    c. Coefficient of rugosity
H. Existing Structures (if exist within about 500 m. from proposed site)
    a. MFL Markings
    b. Afflux
    c. Probable Maximum Discharge
    d. Tendency to Scour
    e. Collection of Brushwood during floods
I. Rainfall
    a. Highest rainfall (cm) and duration (hour) in return period OR One-Hour rainfall intensity for the given catchment region [From the records of Central Water Commission]

Iso-Pluvial Maps: These are 'Flood Estimation Reports' for different regions, which give one-hour rainfall particulars for different return periods of 25, 50, and 100 years.

Estimation of Peak Run-Off/Maximum Flood Discharge from Catchment Area & Rainfall Particulars

Empirical formulae for peak run-off from catchment area

Dicken's formula: $Q = CM^{3/4}$

Where:

Q = peak run-off in cum/sec

M = Catchment Area in sq.km

C = 11 to 14 for annual rainfall 60 – 120 cm

= 14 to 19 for annual rainfall more than 120 cm

= 22 in Western ghats

Ryve's formula: $Q = CM^{2/3}$ (Devised for erstwhile Madras Presidency)

Where:

Q = peak run-off in cum/sec

M = Catchment Area in sq.km

C = 6.8 for areas within 25 km of coastal areas

= 8.5 to 19 for areas between 25 and 160 km of coastal areas

= 10 for limited areas in hills

Inglis formula: $\frac{125M}{\sqrt{M+10}}$ (Devised for erstwhile Bombay Presidency)

Where:

Q = peak run-off in cum/sec

M = Catchment Area in sq.km

Rational Formula for peak run-off from Catchment area

Derived Values

Q = Peak Run-off in cum/sec = f (M) , Catchment area M in Ha

t_c = Concentration Time (Hours) = f (L,H) = $(0.87 \times \frac{L^3}{H})^{0.385}$

P = Coefficient of run-off = f (Catchment area characteristics – area/shape/slope, porosity of soil, vegetation cover, storage characteristics, initial wetness) – Empirically given by a table

Vc = Minimum Vertical Clearance/Free Board = f (Design Discharge)

I_0 = One Hour Rainfall = $\frac{F}{2} \times (1 + \frac{1}{T})$; Parameters

I_C = Critical Intensity of a catchment = $I_0(\frac{2}{1+t_c})$

f = Mean Intensity factor based on catchment area

Peak Run-Off (flood discharge) based on Catchment Area:

Q = $0.028 \times P \times f \times A \times I_c$ =$0.028 \times P \times f \times A \times I_0 \times (\frac{2}{1+t_c})$

= $A \times I_0 \times \lambda$, where λ= $\frac{0.056 \times f \times P}{1+t_c}$

I_0 measures the role played by clouds and λ that by catchment in producing run-off

Random Notes

- Design Loading for Small Culverts and Small Bridges on Rural Roads: 2-Lane IRC Class A
- Mean Velocity of flow = 0.80 of Surface Velocity

Estimation of Peak Run-Off/Maximum Flood Discharge from the Conveyance Factor and Slope of the Stream

The method is suitable for streams with rigid boundaries (Bed and Banks) – i.e., the shape and size of the cross section is same during the flood and after its subsidence.

Velocity can be obtained from Manning's Formula

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

Discharge Q = A x V (cum/sec)

Where:

n = Rugosity Coefficient, which depends on the characteristics of the stream
R = Hydraulic Mean Radius/Depth = Cross Sectional Area /Wetted Perimeter = A/P (m)
S = Longitudinal Slope of the stream taken over a length (depends on Catchment area) U/S and D/S

Determination of Lacey's Silt Factor (k_{sf})

A. ***For Non-Clayey Soils (including boulder strata)***: $k_{sf} = 1.76\sqrt{d_m}$,

where d_m is the weighted mean diameter (mm) of the erodible granular material of the stream.

Determination of d_m and k_{sf} based on type of bed material:

Type of Bed Material	d_m	k_{sf}
Coarse Silt	0.04	0.035
Silt/Fine Sand	0.081- 0.158	0.5 – 0.6
Medium Sand	0.233 – 0.505	0.8 – 1.25
Coarse Sand	0.725	1.5
Fine Bajri/Sand	0.988	1.75
Heavy Sand	1.29 – 2.00	2.0 – 2.42

Determination of d_m based on sieve analysis, and substitute same in the formula $k_{sf} = 1.76\sqrt{d_m}$

[As per Appendix 2 of IRC-5/Plate 4 of IRC-SP-13 (2022)]					
IS Sieve	Sieve Opening (mm)	Average Size of Particle (mm)	Weight of Soil Retained (gm)	% Weight of Soil Retained	% Weight of Particle
(1)	**(2)**	**(3)**	**(4)**	**(5) = 100(4)/W**	**(6) = (3) x (5)**
5.6 mm	5.6	0	0	0	0
4 mm	4	4.8		0	0
2.8 mm	2.8	3.4		0	0
1 mm	1	1.9		0	0
425 µ	0.425	0.7125		0	0
180 µ	0.18	0.3025		0	0
75 µ	0.075	0.1275		0	0
PAN	0	0.0375		0	0
Total Weight of Sample			**W = Column Sum**	**0**	**X= Column Sum**
Weighted Mean Diameter (mm) of the bed soil d_m =					X/100

Data Input Cell

B. ***For Clayey Soils*** (Angle of Repose φ ≤ 15° and Cohesiveness > 0.20 kg/cm^2): $k_{sf} = F(1 + \sqrt{c})$,

Where F = 2.00, for φ ≤ 5°

= 1.75, for 5° < φ ≤ 10°

= 1.50, for 10° < φ ≤ 15°

Alluvial Streams – Lacey's equations

Based on erodibility of bank and/or bed materials streams are classified as:

- ***Rigid boundary Streams***: Streams whose banks and bed consist of non-erodible materials (rock/mixture of sand and clay etc), which do not erode at the maximum velocity during floods. The cross section/slope of such streams remain same during the flood and after its subsidence
- ***Alluvial Streams***: Streams whose banks and/or bed consist of loose granular materials, which erode at prevailing velocities of the stream. During floods the bed/bank materials are picked-up, transported, and deposited - resulting in scouring and silting at different sections of the stream. Hence the it is not possible to ***measure*** the slope and cross section of such streams during floods, but must evolved from ***theoretical premises***.
  - ***Wholly Alluvial Streams***: Streams with banks and beds consisting of erodible (loose granular) materials
  - ***Quasi-Alluvial Streams***: Streams with rigid (non-erodible) banks and erodible (loose granular) beds

Lacey's Theory: Alluvial streams during long periods of floods and subsequent subsidence, tend to scour and silt up till it has acquired such a stable cross section (and more specifically) such a stable slope – that the resulting velocity is '***non-silting and non-scouring***'. When this happens, the stream becomes stable and maintains its acquired shape and cross section, and the stream is said to have come to 'regime'

Lacey's Regime Equations: When an alluvial stream carrying a known discharge Q comes to regime, it will have fixed physical parameters (Area-A, Wetted Perimeter-P, Hydraulic Mean Radius/Depth-R, Slope-S, and Velocity-V) and they are dependent only on two independent entities – Q (Discharge) and k_{sf} (Silt Factor). The equations are given below

$$P = 4.80\sqrt{Q}\ , R = 0.473\left[\frac{Q}{k_{sf}}\right]^{1/3}, S = \frac{0.0003{k_{sf}}^{5/3}}{Q^{1/6}}, V = 0.44Q^{1/6}{k_{sf}}^{1/3}, A = \frac{2.3Q^{5/6}}{{k_{sf}}^{1/3}}$$

Lacey's Equations for Wide Streams: For wide streams (width is very large compared to the depth), The ***stable*** width ***W*** can be taken as wetted perimeter ***P***, and depth ***D*** can be taken as hydraulic mean depth ***R***

$$W = 4.80\sqrt{Q}, D = 0.473\left[\frac{Q}{k_{sf}}\right]^{1/3}$$

Normal Scour Depth

[Scour is a concern only for alluvial and quasi-alluvial streams, and not streams with rigid beds]

Necessity: The ***Depth of the Foundations*** is fixed in relation to the ***Maximum Scour Depth***, which in turn is inferred from the ***Normal Scour Depth***.

Influencing Factors

- Nature of Stream – Wholly Alluvial/Quasi-Alluvial/Rigid-Boundaries
- Width of the Stream in relation to Depth – Wide Stream (Width >> Depth)
- Contraction – LWW (Linear Water Way) is Less than W (Un-Obstructed/Regime Width of the stream)
- Bed Protection

Wholly Alluvial Streams

Case 1: Wide Stream (width is very large compared to depth) and with no contraction of regime width:

$D = 0.473 \left[\frac{Q}{k_{sf}}\right]^{1/3}$ (As per Lacey's equation for wide and wholly alluvial streams)

Case 2: Stream is Contracted, i.e., L (Liner Water Way) is less than the regime width:

$d_{sm} = 1.34 \left[\frac{{D_b}^2}{k_{sf}}\right]^{1/3}$ [Where Db = Discharge(cum/sec) per meter width = Q/L]

Quasi-Alluvial Streams (Banks are non-erodible and Bed is erodible)

Note: The stream does not acquire regime width due to non-erodible banks – Width of the Stream is '**W**'

Case 1: $D = d\left[\frac{Q}{q}\right]^{3/5}$ [Where q and d are measured discharge and depth (based on assessed scour line) based on Mannings equation - $V = \frac{1}{n}R^{2/3}S^{1/2}$]

Case 2: The stream is wide (width is very large compared to depth)

Case 2.1: Velocity 'V' during High Flood is known: $D = \frac{Q}{WV}$

Case 2.2: Slope 'S' of the stream is known: $D = \left[\frac{nQ}{WS^{1/2}}\right]^{3/5}$

Case 2.3: Neither Maximum Flood Velocity 'V' not Slope of the stream 'S' are know: $D = \frac{1.21Q^{0.63}}{{k_{sf}}^{0.33}W^{0.60}}$

Case 3: The Stream is Not Wide

Case 3.1: Stream not Contracted (L – Linear Water Way, is same as W – Regime/un-obstructed width of stream): Normal Scour Depth D, must be worked out based on assumed scour lines and tallying with the calculated discharge with the Flood Discharge

Case 3.2: Stream is Contracted, i.e., L (Liner Water Way) is less than the regime width:

$D = 1.34 \left[\frac{{D_b}^2}{k_{sf}}\right]^{1/3}$ [Where Db = Discharge(cum/sec) per meter width = Q/L]

Maximum Scour Depth

Rules for calculating Maximum Scour Depth from Normal Scour Depth

1. For average conditions on a straight stream and when the bridge is a single span structure, the Maximum Scour Depth is 1.27 times Normal Scour Depth, modified for the effect of contraction if necessary
2. For bad sites on curves, or where diagonal currents exist, or the bridge is multi-span structure, the Maximum Scour Depth is taken as 2 times the Normal Scour Depth, modified for the effect of contraction if necessary *[Note: At Piers it is twice the Normal Scour Depth and at Abutments it is 1.27 times the Normal Scour Depth. But if the spans are small or if over-topping condition for banks exist, then the maximum scour depth at abutments should also be taken as twice that of normal scour depth]*

Depth of Open Foundations for Bridges

- Rule (1) for Soils: The minimum depth of open foundations shall be up to stratum having adequate bearing capacity but not less than 2.0 m below the maximum scour level
- Rule (2) for Non-Erodible Soils: When substantial stratum of non-erodible material at the calculated maximum velocity is encountered at a level higher (or just below) that given by Rule(1), then foundations shall be anchored into that material to a depth of
  - Hard Rock Strata: 0.60 m with a minimum ultimate crushing strength of 10 MPa
  - Other Materials: 1.50 m
- Rule (3) for All Soils: The pressure on foundation material must be well within the safe bearing capacity of that material

Vertical Clearance, Span, and Number of Spans

Vertical clearance is fixed based on the discharge [Table 12.1 of IRC-SP-13 (2022)]

Flood Discharge (cum/sec)	Minimum Vertical Clearance (mm)
Up to 0.30	150
Up to 3.0	450
Up to 30	600
Up to 300	900
Up to 3000	1200

Economical Span: For RCC Slab Bridges – S = 1.5 H,
Where:
H = Total height of abutment/pier from the bottom of foundation to the top after adding vertical clearance in meters
S = Clear Span in meters

Number of Spans:

- If the required Linear Water Way 'L' is less than the economical span, then it must be provided in one single span
- Else Number of Spans N = L/S, where S may be modified suitably so that N is a whole number. Multiple spans of varying span lengths may be provided from the economical point of view as well as to minimize obstruction to the flow