HYDROLOGICAL AND MORPHOLOGICAL CONSIDERATIONS FOR DECIDING LOCATION, WATERWAY, AFFLUX AND SCOUR IN RIVER BRIDGES

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HYDROLOGICAL CONSIDERATION

- Hydrological study is most important for determination of design flood of required frequency
- IRC recommends flood of 1 in 100 years return period for design of bridges irrespective of length
- Climatic changes which are occurring these days need deeper study for finding design flood
- Digital Elevation Model (DEM) from Remotely sensed data and softwires are extremely helpful
- ArcGIS and HEC Geo may be used for delineation of catchment area from digital elevation model
- Other than the Indus-Ganga-Brahmaputra Basins for which discharge data is restricted, time series of water level and discharge data are available from National Water Informatics Centre
- For small catchments, peak flood may be computed using the rational formula
- For medium catchments, CWC flood estimation reports for different zones in India are reliable
- Direct determination of flood from G-D data should be used for frequency analysis

MORPHOLOGICAL CONSIDERATION

- River morphology is the field of science dealing with changes of river planform and shape of cross-section due to flow of water and sediments and erosion processes mainly during floods.
- Studies on the river morphology provide important information required for the management of water resources, constructions of hydraulic structure like dams, barrages, bridges, intakes, aqueducts, syphon aqueducts, river training works etc.
- Innumerable bridges are to be constructed all over India for increased connectivity. To avoid many unforeseen problems in future, hydrological and morphological considerations are as important as structural and foundation design of bridges.
- Existing codes by Indian Roads Congress (IRC) e.g. IRC-5, IRC:SP-13, IRC:SP-42, IRC-78, IRC89 etc. provide guidelines for determining design flood, waterway, afflux, scour depths etc. for design of bridges.

WATERWAY

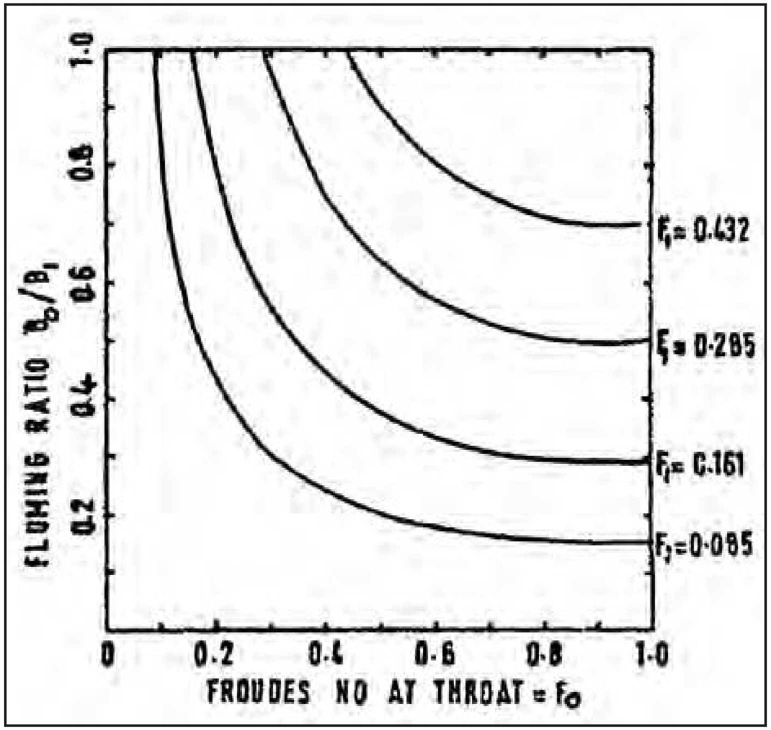
- For natural channels in fine alluvial beds with well-defined banks linear waterway corresponding to the design flood discharge is the distance from bank to bank where the design HFL meets the bank.
- For undefined banks, the linear waterway (W) recommended as per IRC guidelines is based on Lacey's regime equation , W=C (Q)0.5Where. Q is design flood discharge of 100 year return period and C is a constant varying from 4.8 to 6.3.
- The above equation applicable for flood plains is not applicable for mountainous and hilly region where the river bed is made of coarse soil like gravels and boulders.
- In trough region where river sheds huge quantity of sediments due to sudden flow expansion such regime equation is not applicable.
- As per Brown-Einstein equation qs Ss α q2S2 where q and qs are water and sediment flow rate per unit with of river respectively, Ss is specific gravity of sediments and S is longitudinal bed slope of river. River is found to change its course frequently due to deposition of sediments

RESTRICTION OF WATERWAY

- For economy. linear waterway is often restricted. Such restrictions cause higher afflux upstream of the bridge. IRC codes simply mention that afflux due to restriction should not be harmful without giving any guideline for computing restriction of waterway.
- If B_1 is the mean width of an approach channel and B_0 is the restricted width, it can be proved that the constriction ratio is given by the following equation

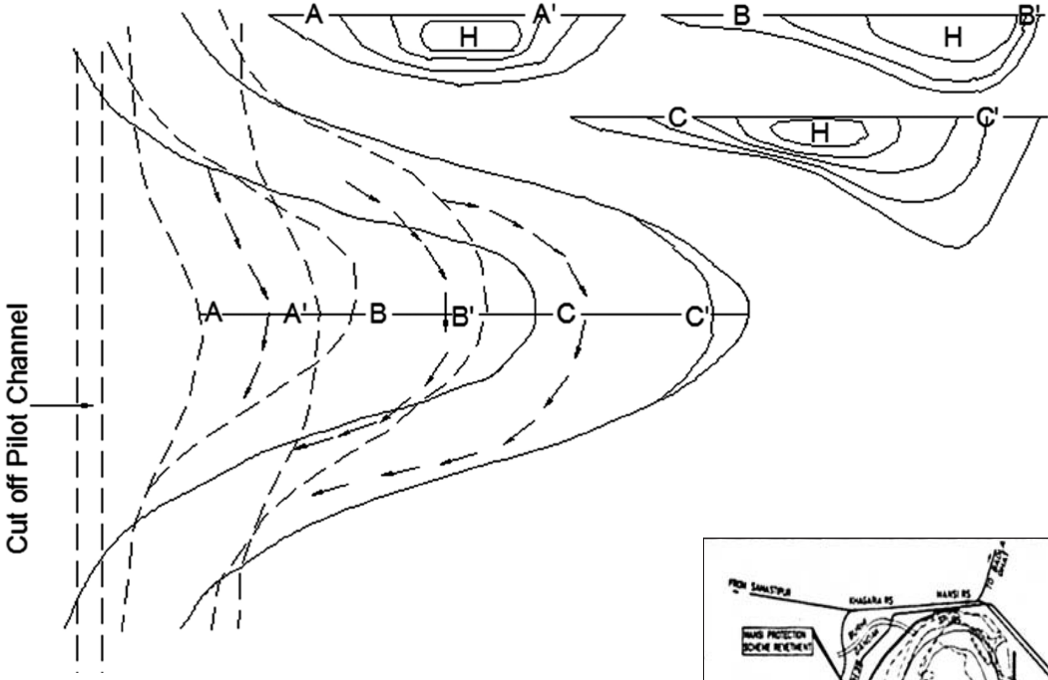
$$B_o/B_1 = (F_1 / F_o) [(2+F^2{}_o) / (2+F_1{}^2)]^{3/2}$$

- It may be seen that opportunity of fluming a channel is low with increasing F_1-values.
- F_0-value exceeding 0.6 create flow undulation and high afflux. When F1>1.0, flow is choked creating hydraulic jump downstream .
- In mountainous rivers where F_1>1.0 and flow is supercritical, flow will be choked creating hydraulic jump downstream. Fluming should be avoided so that river carries water and sediments unhindered.

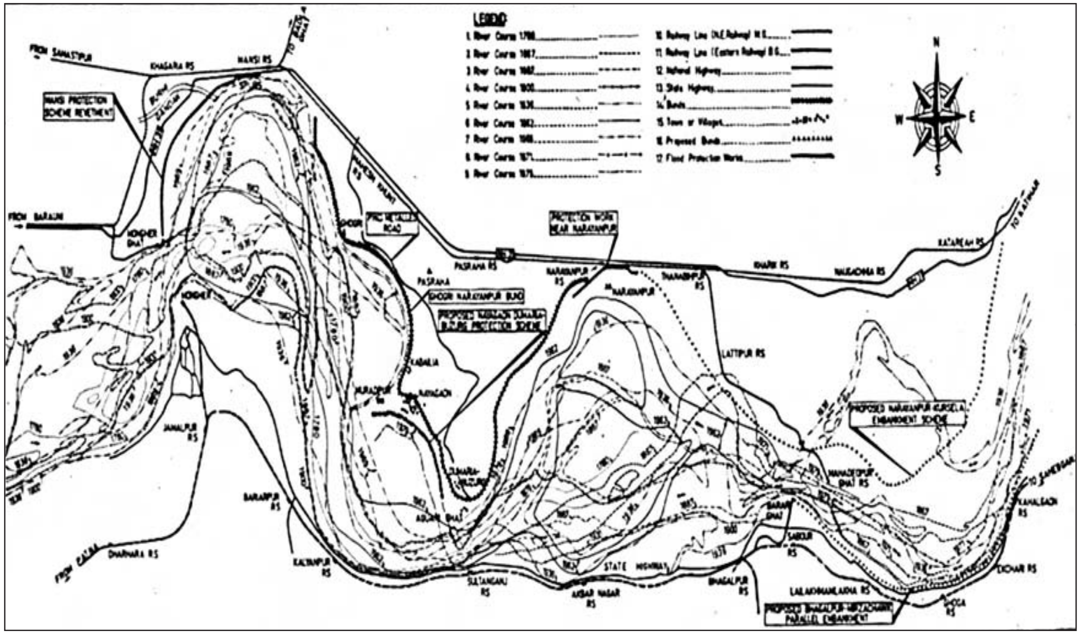


Relation between B_0/B_1 against F_0 for different F_1-

RIVER MEANDERING

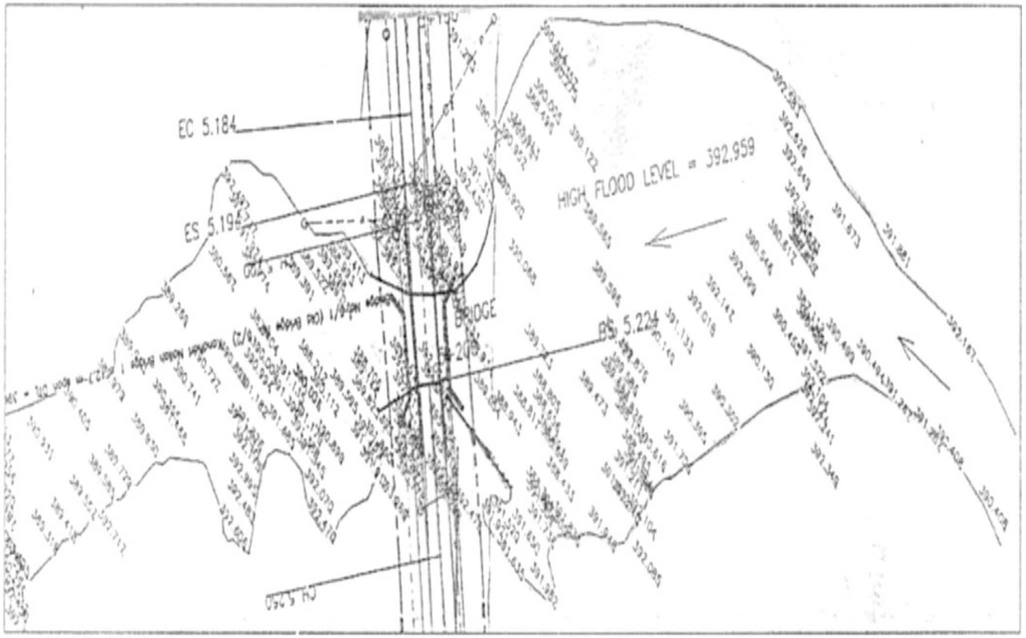


Meandering processes



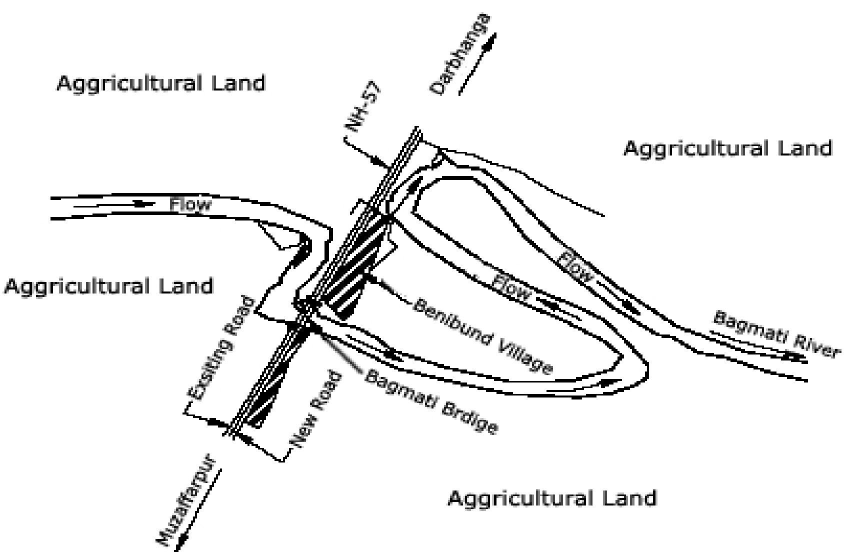
Meandering river Ganga from Prayagraj/Allahabad to Patna

EXAMPLES OF SCOURING/MEANDERING WITH RESTRICTED WATERWAY

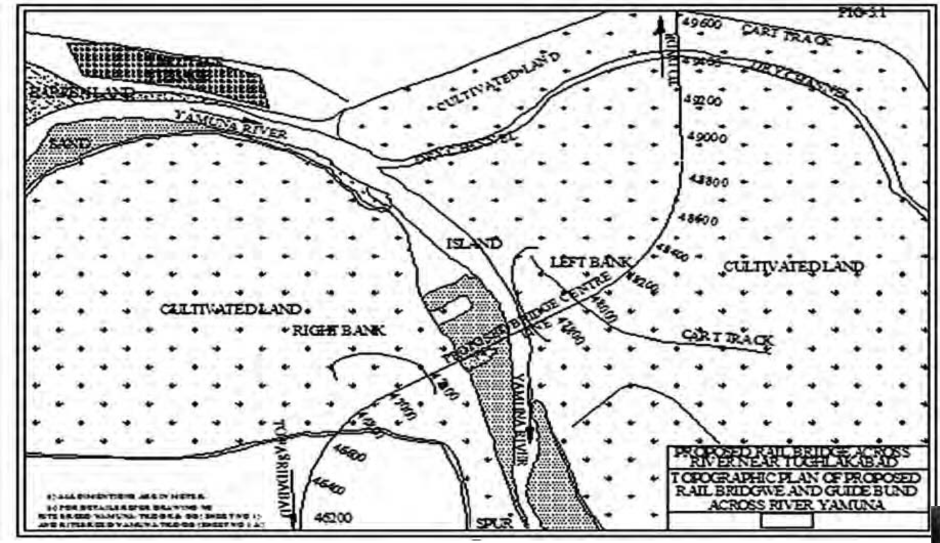


Scouring of river banks near a bridge on NH-6

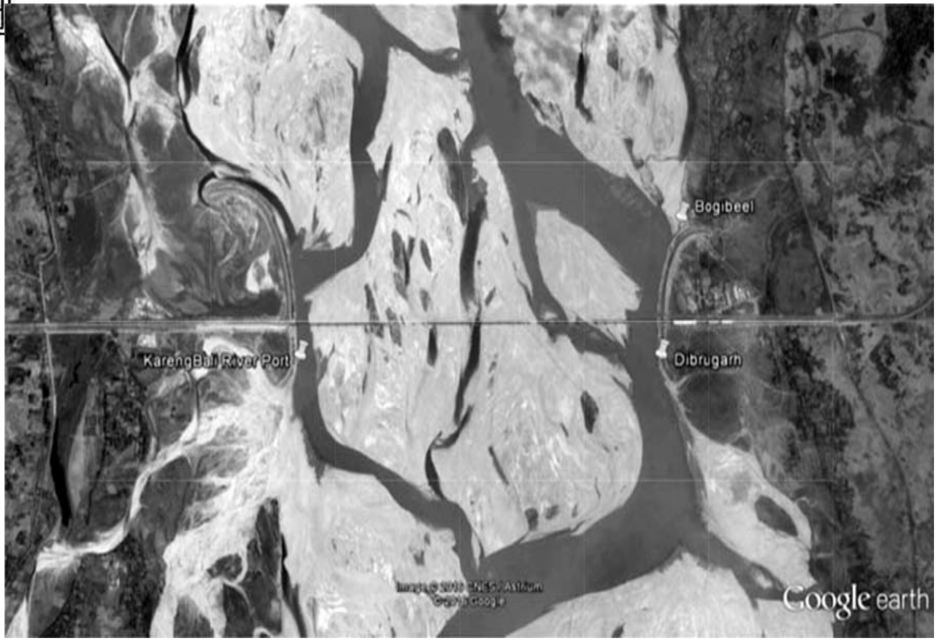
Meandering River Bagmati near bridge on NH-57



RESTRICTED WATERWAY FOR BRIDGE ON YAMUNA RIVER



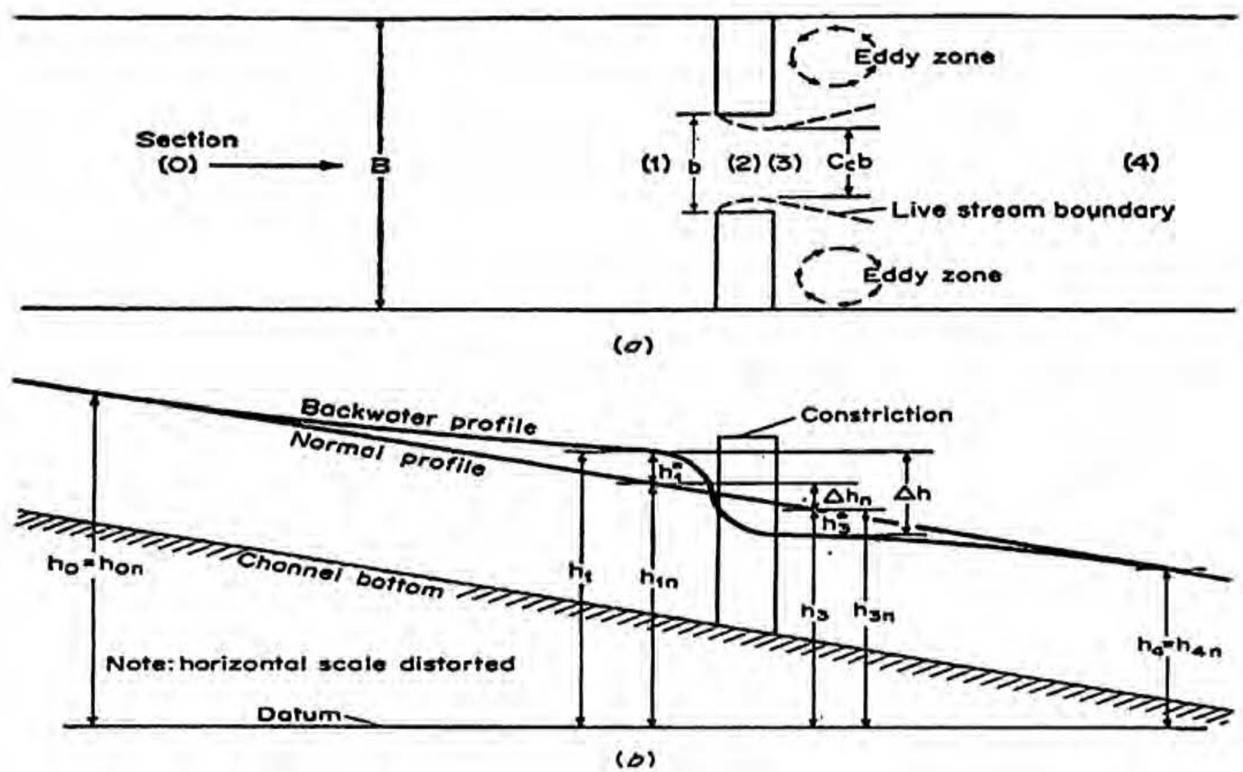
530 m long Bridge on Meandering Yamuna, Yamna river at Delhi - flood Plain width 2500m



4.9km long Bridge on Braided River Brahmaputra at Bogibeel, Aasam-- Flood plain width 8.4 km

AFFLUX IN BRIDGES

Afflux occurs upstream of a bridge due to head losses. Greater the restriction of waterway, higher will be the afflux(h_1^*) and more will be the backwater reach as shown in figure. Excessive afflux not only causes submergence of land and properties , it leads to siltation due to slack flow and flow instability both upstream and downstream of the bridge.



Plan (a) and Sectional View (b) of a river Showing Afflux (h_1^*) and Backwater Profile due to restriction of waterway

AFFLUX IN BRIDGES (Contd.)

- IRC guidelines prescribe Molesworth equation for computation of afflux.

$$h_1 * = [V_1^2 /17.88 + 0.015] [(A_1/A_0)^2 - 1]$$

- The above formula is applicable for a straight river with defined section.
- In wide rivers with large flood plains give wrong results and low afflux. Bradley formula given below should be used in such conditions.

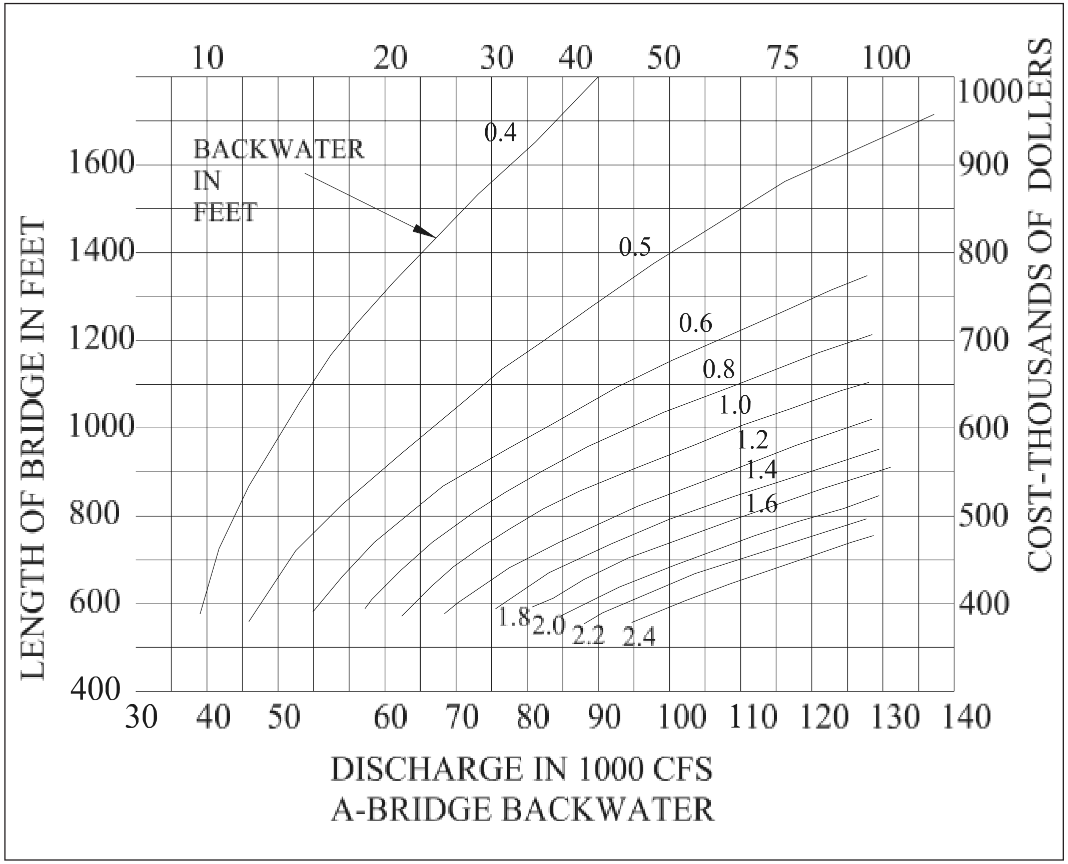
$$h_1 * = 3 * (1-M) * V_n^2/2g$$

- A composite hydraulic design curve was plotted by Bradley (1970) for a particular river in USA with meandering flood plain as shown below.
- The designer can read from the figure the length of bridge required to pass various flows with a given backwater.
- To illustrate use of the resulting chart; suppose it is decided to design the bridge for a 50-year recurrence interval. If 1.5 feet (45.7 cm) of backwater can be tolerated, the bridge can be 780 feet(238m) long at a cost of $520,000.

AFFLUX IN BRIDGES (Contd.)

- While if the backwater must be limited to 0.6 foot (18.3cm) the bridge length required would be 1,350 feet(412m) at a cost of $870,000 i.e. $350,000 more.

- To stay within a certain limiting rise of water surface can mean a relatively large increase in the cost of a bridge.



Length and Cost of Bridges Against Design Flood for Different Values of Afflux (Bradley, 1978)

BRIDGE SCOUR

- Determination of scour depth in bridge piers and abutments is needed for foundation design.

- Present guidelines of IRC-78 is to find total scour depth below design HFL as 2R where R is regime depth given by Lacey's equation:

$R=0.475\,(Q/f)^{1/3}$ where there is no restriction of waterway and

$R= 1.34\,(q2/f)^{1/3}$ where the waterway is restricted and f is silt factor given by

$f = 1.76\,(d_{50})^{1/2}$

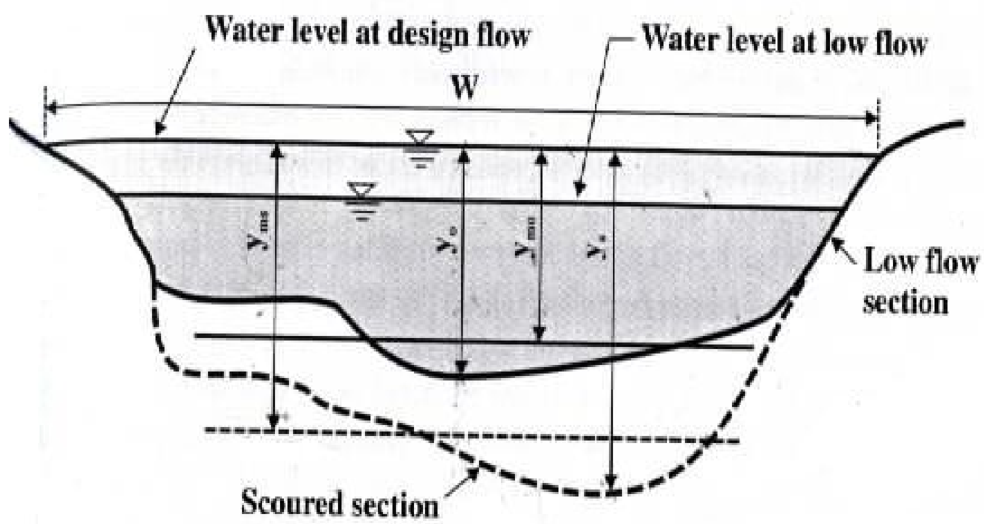
- In the above equations, Q is the design flood discharge in m^3/s, q is the discharge intensity in $m^3/s/m$, d50 is then sediment size in mm and R is regime depth in meter.

- Above method is not scientific since scour is governed by many more parameters other than Q and f.

- Scour below design HFL should be found as sum of general scour, contraction scour and local scour as detailed below.

GENERAL SCOUR

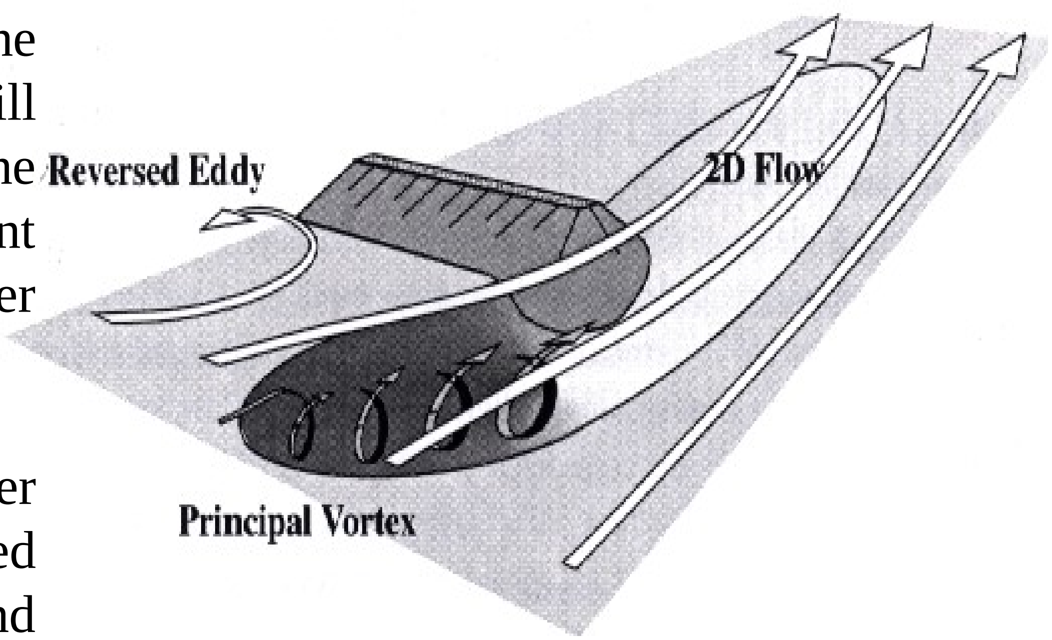
- General scour is the lowering of river bed usually during the passage of a flood in a river.
- Several hydrological and manmade factors e.g. construction of dams and barrages, flood embankments, sand mining from river bed etc.
- Short-term general scour develops during a single or several closely-spaced floods and long-term general scour takes place over longer time scale, normally of the order of several years or longer, and includes progressive degradation and lateral bank erosion.
- As illustrated in Fig., low water bed level (indicated by solid line) usually retrogrades during the flood causing lowering of bed level (indicated by dotted line) due to high velocity of flow.



Illustrating General Scour

CONTRACTION SCOUR

- Contraction scour occurs at bridge site when the normal width of river is contracted laterally by constructing abutments within the flood plain as well as obstruction by the piers.
- Area of the contracted section increase by further lowering of river bed. As the area of the contracted section increases till the sediment transport under the bridge equals the sediment transported in the normal river section.
- High velocity /shear stress under the bridge causes river bed erosion under/near the bridge and consequent erosion of bed materials.



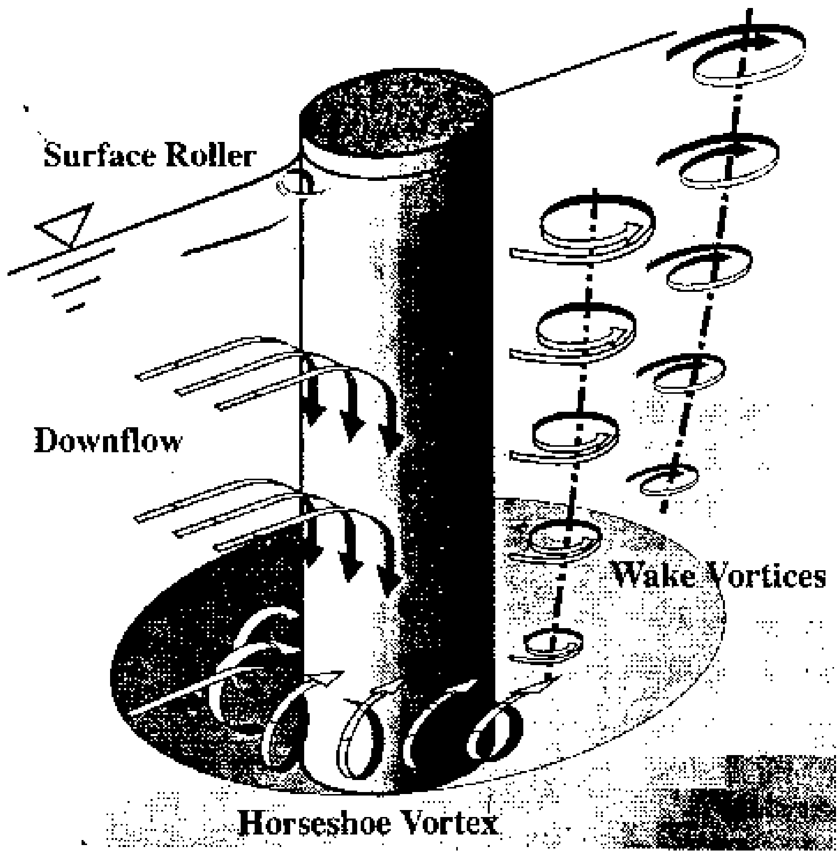
Local scour due to Lateral Contraction of River by Abutment/approach embankment

LOCAL SCOUR AT PIERS AND ABUTMENTS

- Local scour at piers and abutments is caused by the formation of vortices due to obstruction of flow
- The horse shoe vortices at the pier/abutment base due to differential pressure head formed by higher potential at top (due to stagnation pressure) compared to the pressure head at the bottom where flow velocity is low.

- The downflow combined with horseshoe vortex create complex flow pattern near the pier base and scour hole formed at the bottom.

- It generates wake vortices and scoop out the sediments at river bed like a vacuum cleaner resulting in local scour in the vicinity of pier/abutment.



Local Scour near a Circular Pier in a Bridge

LOCAL SCOUR AT PIERS AND ABUTMENTS (Contd.)

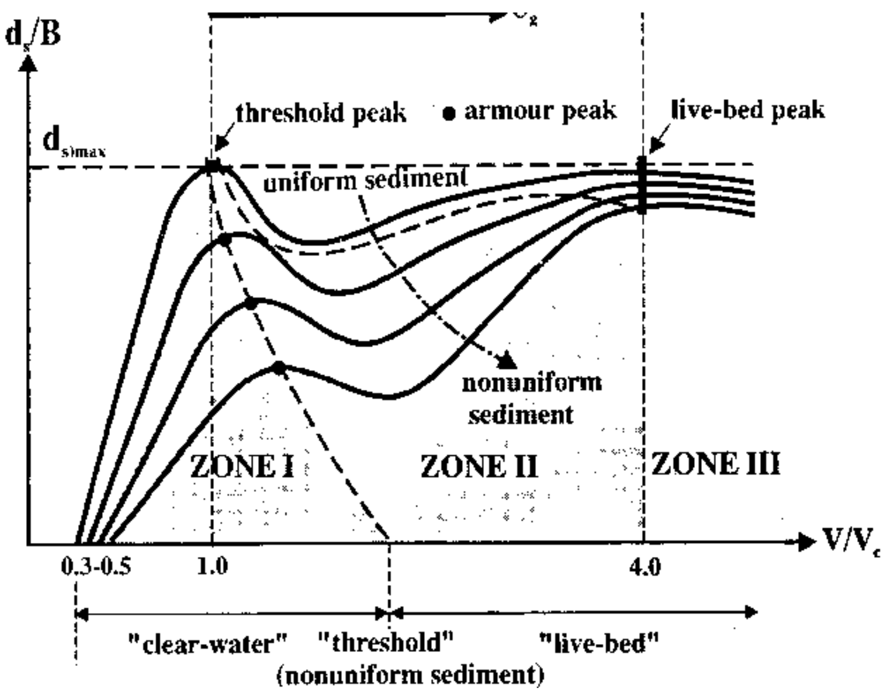
- Local scour fluctuates due to the migration of river bed under live bed condition. Maximum scour depth (d_{smax}) occurs under clear water condition and it is about 10% more than that /under live bed condition. Scour depth reduces with non-uniformity of sediments.

- It is now universally, established that d_{smax} stabilises when $V=V_c$ for clear water condition and for live bed condition, it stbilises at $V=4V_c$.

- Flow pattern in bridge abutments varies according to the length of abutment.

- Flow pattern in short abutments are similar to pier. Large circulating reverse eddy is generated ahead of the abutment.

- Scour activity is strongest near the end of abutment adjacent to bridge proper where the principal vortex is strongest.



Local Scour (d_s) Variation with Flow Velocity (V)

PARAMETERS GOVERNING LOCAL SCOUR

- Different parameters governing local scour may be grouped as follows:
- (i) Flow parameters e.g. ρ, μ, V, y, G, g, Fr
- (ii) Sediment parameters e.g. d_{90}, d_{84}, d_{50} d_{16}, ρ_s,V_c ,σ_g
- (iii) Bridge/abutment geometry e.g. b, Sh, L, Al (θ), t , t_e
- ρ is density of water, μ is coeff. of dynamic viscosity, V is flow velocity under the bridge, y is flow depth in front of pier/abutment, G is a parameter governing lateral distribution of flow, g is acceleration due to gravity, F_r is Froude's no. of flow given by the relation $Fr = V/(gy)^{0.5}$.
- d_{90}, d_{84}, d_{50} d_{16} sediment sizes passing through by weight corresponding sieve sizes respectively, ρ_s is sediment density, V_c is critical or threshold velocity at which the bed becomes live i.e. bed sediments start moving in the river, σ_g is geometric non-uniformity of sediments given by the relation $\sigma_{g=} (d_{84}/d_{16})^{0.5}$. b is width/thickness of pier, Sh is shape of pier nose, Lis length of pier (wall type) and abutment, Al is alignment factor given by flow obliquity with respect to flow axis (θ), t is flood duration, t_e is time to reach equilibrium scour.