RIVER EROSION DOWNSTREAM OF A BARRAGE

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SYNOPSIS

Large number of weirs and barrages have been constructed in India for diversion of flow for irrigation, hydro-power, industrial uses etc. River erosion downstream of barrages poses threat to lead to the safety of the structure and loss of properties in the adjoining areas. This paper deals with the possible causes of such erosion so that effective anti erosion measures can be adopted.

1.0 INTRODUCTION

Barrages are constructed on rivers for diversion of flow for varities of uses e.g. irrigation, hydro-power, industrial and municipal uses, navigation, etc. Inspite of protective measures, heavy damages are reported to have occurred due to erosion of river bed and banks downstream of barrages. As reported by CWC (1983), river Kosi had breached both the eastern and the western embankments downstream of Bhimnagar Barrage bringing in collosal loss of life and properties. Properties worth hundreds of crores of rupees have been eroded by the river Ganga downstream of Farakka Barrage. It is extremely important to investigate, therefore, river erosion downstream of a barrage so that the protective works and river training measures can be made more effective.

2.0 Regime Consideration

Flow in Indian rivers varies widely during monsoon and non-monsoon seasons and also over the years. Lacey's regime depth (R) and regime width (P) in meters are given by the relations:

$$R = 0.473\ (Q/f)^{1/3} \qquad \ldots(1)$$

$$P = 4.75\ Q^{1/2} \qquad \ldots(2)$$

where Q is the flow in cumec and f is the silt factor. Obviously, for a given bed and bank material, R and P values will increase with increase in the flow. In other words, a river will erode both bed and the banks to attain a stable regime section for a given flow Q. Higher the flow, greater will be the tractive stress and more will be the erosion.

3.0 Retrogression of River Bed

River flowing in alluvial bed is found to retrograde downstream of barrage due to deposition of sediments upstream of the barrage and comparatively clear water flow downstream. It has been proved that with the same flow at the same depth, tractive stress in clear water will be higher than that with silt-laden water. This is due to dampening of eddy viscosity in a silt-laden flow. River downstream of a barrage will continue to pick up silt from bed and banks till the equilibrium silt charge is built up.

4.0 Inadequate Energy Dissipation

Construction of a barrage on a river creates afflux resulting in difference in energy level upstream and downstream of the barrage, ΔE, as shown in fig.1. If the energy dissipating device is not properly designed, there

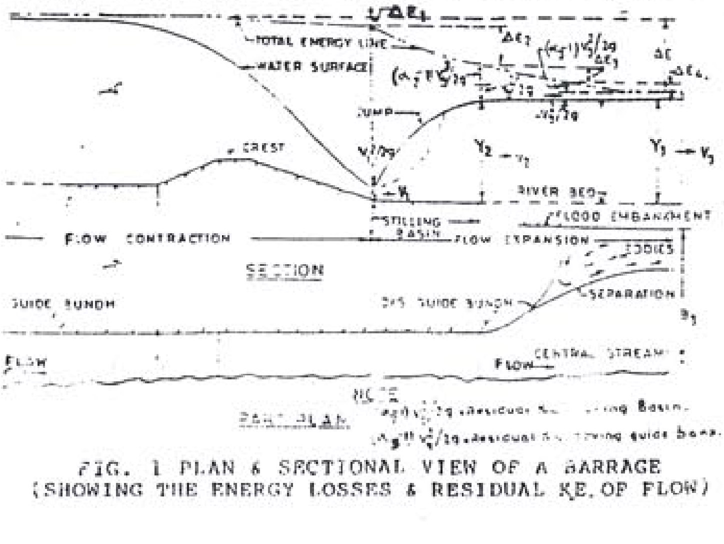

FIG. 1 PLAN & SECTIONAL VIEW OF A BARRAGE
(SHOWING THE ENERGY LOSSES & RESIDUAL KE. OF FLOW)

will be undissipated energy leaving the basin in the form of residual kinetic energy of flow. Moreover, a given energy dissipating structure designed for a given flow may not be effective at other flows. Another important reason may be the approach flow Froude's number (F_1) before the hydraulic jump. It is known that in the region $2.5 < F_1 < 4.5$, the hydraulic jump is oscillating and unstable due to inefficient jump formation. Incidentally, prejump Froude's numbers (F_1) corresponding to design maximum flow are found to be 3.0 and 2.0 in Kosi Barrange and Farakka Barrage respectively. Higher is the residual kinetic energy of flow in the tail channel more will be the river erosion downstream of the barrage. Primary purpose of this paper is to focus attention on this aspect as reported in the subsequent paragraph.

5.0 Flow Concentration and Flow Instability

When a barrage is constructed on the alluvial flood plain of a river, the waterway provided is less than the khadir width. For example, Kosi barrage has a length of 1150 m compared to the khadir of 6,900 m width. Corresponding figures in case of Farakka barrage are 2135 m and 5000 m respectively. I.S. Code (1973) recommends looseness factor less than unity for flushing out of sediments in hilly and mountaneous reaches. Partial operation of gates during lean flow and the conventional technique of maintaining deep channel near head regulator are also responsible for ~~two~~ flow concentration. As shown in fig. 1 the river flow undergoes con~~s~~traction upstream and expansion downstream of a barrage. Although contraction of flow is an efficient process, flow expansion is not, especially where the expansion is abrupt as in the downstream reach of the guide bundh, where there is hardly any recovery of head. The flow separates from the boundary resulting in flow concentration, flow distortion and flow instability. Such unstable & distorted flow can cause ~~severe~~ erosion of bed and banks in the downstream reach, till all the residual kinetic energy of flow is completely dissipated.

6.0 Residual Kinetic Energy of Flow and River Erosion

6.1 Fig. 1 shows the typical plan and section through a barrage. The total loss of energy (ΔE) is given by

$$\Delta E = \Delta E_1 + \Delta E_2 + \Delta E_3 + \Delta E_4 \quad ..(3)$$

where ΔE_1 is the loss of energy upstream of the stilling basin mainly due to friction, ΔE_2 is the energy loss brought about by turbulence in hydraulic jump, ΔE_3 is the loss of energy downstream of stilling basin in the guide bundh region through friction & turbulence and ΔE_4 is the energy loss which takes place downstream of guide bundh due to separation and eddies. There is flow contraction upto the toe of the downstream glacis followed by flow expansion. Kinetic energy of flow at entry of the basin is $V_1^2/2g$ as the flow is almost uniform. Kinetic energy of flow at the exit end of the basin is $\alpha_2 V_2/2g$, since the flow is non-uniform after the hydraulic jump. Here α_2 is the Corrioli's coefficient and is given by

$$\alpha_2 = \frac{\int u^3 \, dA}{A_2 V_2^3} \quad ...(4)$$

where u is the local velocity of the flow through an elementary area dA, A_2 is the area of flow section at the exit of the basin and V_2 is the corresponding mean velocity of flow. When the hydraulic jump is efficient, $\alpha_2 \approxeq 1.0$. $\alpha_2 > 1$ when the jump is inefficient and the energy dissipation is incomplete in the basin. Residual kinetic energy of flow leaving the basin will be $(\alpha_2 - 1) \times (V_2^2/2g)$. For a given flow with a given depth (and hence a given mean velocity, V_2), residual kinetic energy can be contained only through flow distortion and non-uniformity as shown in fig. 2.

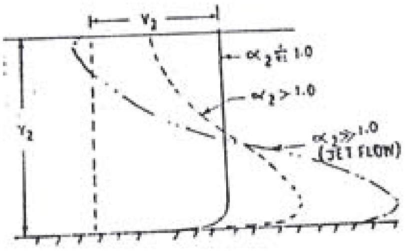

FIG. 2 FLOW DISTORTION ALONG DEPTH DUE TO RESIDUAL KINETIC ENERGY OF FLOW AFTER BASIN.

Higher is the residual kinetic energy, more will be the flow distortion and greater will be the river erosion.

6.2 At the end of guide bundh, the flow undergoes a sudden expansion with practically no recovery of head i.e. $Y_2 \approxeq Y_3$ although mean velocity of flow further reduces from V_2 to V_3. The flow downstream of guide bundh is distorted further due to the residual kinetic energy of flow $(\alpha_3 - 1)$. $V_3^2/2g$ where

$$\alpha_3 = \frac{1}{A_3 V_3^3} \int u^3 dA \quad ...(5)$$

here A_3 and V_3 are the flow area and mean flow velocity downstream of guide bundh.

It may be mentioned here that the normal kinetic energy of flow, $V_3^2/2g$, in an alluvial river is extremely small and hence even a small amount of residual kinetic energy will bring about large amount of flow distortion and flow non-uniformity as shown in fig. 3. It has been found that even 1% residual kinetic energy is sufficient for a rise of α_3 to 2.5 and 2% residual energy, may raise α_3 to 6. Higher is the residual kinetic of flow more will be non-uniformity and flow distortion resulting in erosion of bed and banks of the river downstream. Such flows are extremely unstable (Mazumder, 1988) due to mass exchange between the central stream and the side eddies and the jet may wander from one bank to the other, causing erosion of both the banks.

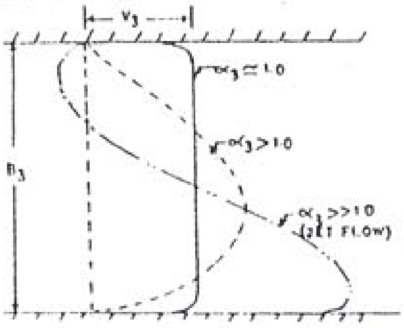

FIG. 3 FLOW DISTORTION ALONG WIDTH OF A RIVER DUE TO RESIDUAL KINETIC ENERGY LEAVING DOWNSTREAM OF GUIDE BUNDH

7.0 CONCLUSION

(i) Residual Kinetic energy of flow arises due to either incomplete energy dissipation within a stilling basin or non-recovery of head in the abruptly expanding guide bundhs.

(ii) Residual kinetic energy of flow is contained by flow distortion and non-uniformity. Higher is the residual kinetic energy greater will be the distortion & non-univormity of flow.

(iii) Since the normal kinetic energy of flow in a river in alluvial flood plain is extremely small, there will be large distortion of flow even with small percentage of residual kinetic energy.

(iv) Distorted flows cause high concentration of flow and flow instability resulting in large amount of erosion of river bed and banks.

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