PLANNING AND DESIGN OF BARRAGE TYPE DIVERSION STRUCTURES ON BOULDERY RIVERS WITH STEEP GRADIENT

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ABSTRACT

The approach of planning and design of diversion structures for hydro electric power generation in upper bouldery reaches of rivers having steep gradient and deep pervious foundation is quite different from those on lower reaches of rivers with fine alluvial soil. There are various issues that are yet to be resolved and as such the existing guidelines by Bureau of Indian Standards for design of weirs and barrages do not apply to the planning and design issues of structures in bouldery reaches. In this paper, authors have discussed the various limitations of applying existing design methodology (for barrages on alluvial flat reaches of river) to barrages on bouldery reaches of river. Outline of alternative designs are also presented.

Keywords: **Diversion structure, Bouldery River, supercritical flow, sediment size, impervious apron, cut-offs, energy dissipation**

INTRODUCTION

Hydro electric power development generally envisages a barrage type diversion structure (of 15 m to 25 m height) in bouldery reaches of a river with steep gradient (ranging from 1:15 to 1:50 or so) and narrows cross section. The bouldery reach of river is characterized by supercritical flow for the major portion of its length till it reaches the plains where the river runs at sub-critical stage. The river bed comprises of boulders, cobbles, gravels, etc. with a mean sediment size (D_{50}) ranging from 10 cm to 30 cm or more. The planning and designing of these structures are entirely different from the design principles followed for structures in mild sloping lower reaches of rivers with flat and plain terrains flowing in fine alluvial soils (D_{50} ranging from 0.2 mm to 2 mm). In fact, current IS codes on 'Guidelines for Hydraulic Design of Barrages and Weirs: Part – I, Alluvial reaches' (IS: 6966 – Part I, 1989) and other related codes (IS: 7720 – 1991, IS: 7349 – 1989) by Bureau of Indian Standards (BIS) are applicable for barrages on alluvial reaches of rivers with fine and medium size sediments. A new code IS: 6966 – Part II for bouldery reaches is under preparation. The design of diversion structures on bouldery reaches should, therefore, be based on the experience gained from the earlier prototypes constructed on such bouldery strata till the time the new code is finalized by BIS. Photographs 1 and 2 give an idea of rivers flowing in bouldery reaches with steep gradient and carrying large size boulders.

Photograph-1: Showing a Typical River in Bouldery Reach

Photograph-2: River in Boulder Reaches during Floods

DESIGN CONSIDERATIONS

Various considerations in the hydraulic design of a barrage include:

- Length and Thickness of Impervious Floor
- Raised Crest Vis a Vis Crest at River Bed Level
- Energy Dissipation Arrangement
- Downstream Cutoff for Protection against Scour
- Downstream Protection Works

These aspects are discussed one by one in subsequent paragraphs.

a. Length and Thickness of Impervious Floor

Khosla's theory is popularly applied to determine the length of impervious floor and depth of downstream cut-off for protection against piping due to sub surface flow for design of diversion structures on rivers with fine and medium alluvial sediments. But in case of bouldery rivers, it is well understood that the piping phenomenon is unlikely to occur due to the heterogeneous characteristics of river bed material and large size of bed particles resulting in armouring of river bed and subsurface flow due to steep gradient. The designer has to endeavour to reduce the sub surface flow and consequently the uplift pressure on the impervious floor. The loss of head of the seeping water will depend upon the upstream depth of cutoff, gradation of soil and nature of valley. Due to these flow conditions, it is difficult to estimate the length of impervious apron and uplift pressure acting on the impervious floor where there is deep pervious foundation. It is advisable to provide approximately 8 m to 10 m deep cut-offs at the upstream and downstream ends of the floor (depending on the scour depth) and at the control block as illustrated in figures 1, 2 & 3 An impervious floor of 150 m to 200 m length shall be considered suitable for a seepage head of about 25 m. The control block of the structure should be kept horizontal so as to facilitate the power intake with a sufficient depth above the barrage floor. The gradation curve plotted for the bouldery strata generally reveals that the mean sediment size (D_{50}) falls in the range of 10 cm to 30 cm. Therefore, due to this coarse gradation, steep slope of river and narrow valley (75 m to 100 m wide), there will be more head loss, less sub-surface flow of water and apparently less uplift on the impervious floor due to three dimensional seepage flow in such terrains. Approximately, a floor thickness of 2 m to 4m is considered to be sufficient depending upon seepage head.

Khosla's theory and Lane's creep theory are applicable for the rivers with the following characteristics:

1. The slope of the river is almost flat / mild (1 in 1000 or less).
2. Fine alluvial soils with mean sediment size ranging from 0.2 mm to 2mm.
3. The flow in the river is sub-critical and seepage flow is by and large two dimensional.

However, due to non – availability of literature in bouldery rivers with deep pervious foundation and relevant data, Khosla's method is still being adopted for calculating the length and thickness of impervious floor and cut-off depths from the conventional exit gradient concept as propounded by Khosla, Bose and Taylor (1954) and published by CBIP (1994).

Table – 1 compares the lengths of impervious floor corresponding to different seepage heads and cut – off depths for a permissible exit gradient of 0.25 as per Khosla's Theory and weighted creep ratio of 3.5 as per Lane's theory.

Table – 1: Conventional method to calculate the length of diversion structure

Sr. No.	Max. Seepage head acting, m	Depth of d/s cutoff, m	Depth of u/s cutoff, m	Khosla's exit gradient factor for shingles	Lane's creep coefficient for gravelly rivers	Length of diversion structure, m	
						Khosla's theory	Lane's weighted creep theory
1	15	6	6	0.25	3.5	115	94
		7	7			97	81
		8	8			83	68
		9	9			71	54

		10	10			62	41
		6	6			210	152
		7	7			178	139
2	20	8	8	0.25	3.5	154	125
		9	9			135	112
		10	10			119	99
		6	6			332	210
		7	7			282	196
3	25	8	8	0.25	3.5	245	183
		9	9			216	170
		10	10			192	157
		6	6			480	267
		7	7			410	254
4	30	8	8	0.25	3.5	357	241
		9	9			315	228
		10	10			282	215

b. Raised Crest Vis a Vis Crest at River Bed Level

For diversion structures to be founded on bouldery strata, a raised crest is not considered desirable as it will cause to accumulate stones, cobbles, gravels etc. behind it. This will in turn demand for higher crest elevation for power intake resulting in higher MDDL and FRL. Therefore, the spillway gates should be provided at the river bed level itself. This will be helpful for effective drawdown flushing of sediments from the reservoir which usually extend up to a length in the range from 300 m to 1000 m depending upon the head. This will also help to keep the power intake area free from sediments.

c. Energy Dissipation Arrangement

Rivers flowing in fine alluvial soils undergo deep scour downstream if the energy dissipation in the basin is incomplete. Usually hydraulic jump type USBR (1958) stilling basins are provided for energy dissipation in such flat terrain. Various alternatives of energy dissipation arrangements in bouldery reaches are listed in Table-2 with a comparative statement on their relative merits and demerits.

Table-2: Different types of energy dissipation arrangements

Type of energy dissipation arrangement	**Relative merits and demerits**
(a)A classical Rectangular USBR type stilling basin (Bradley and Peterka, 1957) With Parallel Side Walls.	Not suitable for bouldery reaches of river with steep slope. The cistern level will be much below river bed due to low tail water depth inadequate for jump formation. The cistern is likely to face heavy churning of boulders resulting in damage to the basin floor. The basin will also get filled with boulders and gravels etc. resulting in repelling of hydraulic jump downstream of basin.

(b)Stilling basin same as(a) but with adversely sloping basin floor as shown (Alessandro & Stefano)	By adopting an adverse slope of 4^0 to 6^0 to basin floor, many problems of classical type stilling basin (a) can be overcome. With adverse slope, net drag on basin floor due to moving boulders will be reduced resulting in less amount of frictional damage.
(c) Stilling basin with rapidly diverging side walls and adversely sloping basin floor (Mazumder-1994)	Performs extremely well even with very low tail water depth. If the piers are extended up to the end of the basin, expanding walls will have hardly any effect on jump performance. In the classical design, it is usual to provide a common stilling basin for all bays. However for independent hydraulic action of individual bays and from stability and structural considerations, it may be desirable to have independent bays with piers extending up to end of stilling basin.
(d)Absence of stilling basin and provision of rigid floor with slope equal to river bed slope	Best suited for passing boulders and sediments during flushing. But there will be very little energy dissipation and hence more scour will take place downstream of the basin where the bouldery bed contains gravels and course materials. Providing cutoffs at the downstream end of basin and protection works downstream of basin may be helpful to cater for the scour due to residual kinetic energy of flow and turbulence.
(e) Use of Flip Bucket Type Energy Dissipater (USBR-1958)	Not considered desirable due to excessive scour downstream by the falling jet and possibility of damage to the bucket itself due to movement of boulders at a high velocity. Flip buckets are not acceptable for low head structures because the performance of the ski jump buckets for the velocities less than 20 m/sec is not satisfactory.

Figures 1, 2 & 3 show the type (a), type (b) and type (d) energy dissipation arrangements discussed.

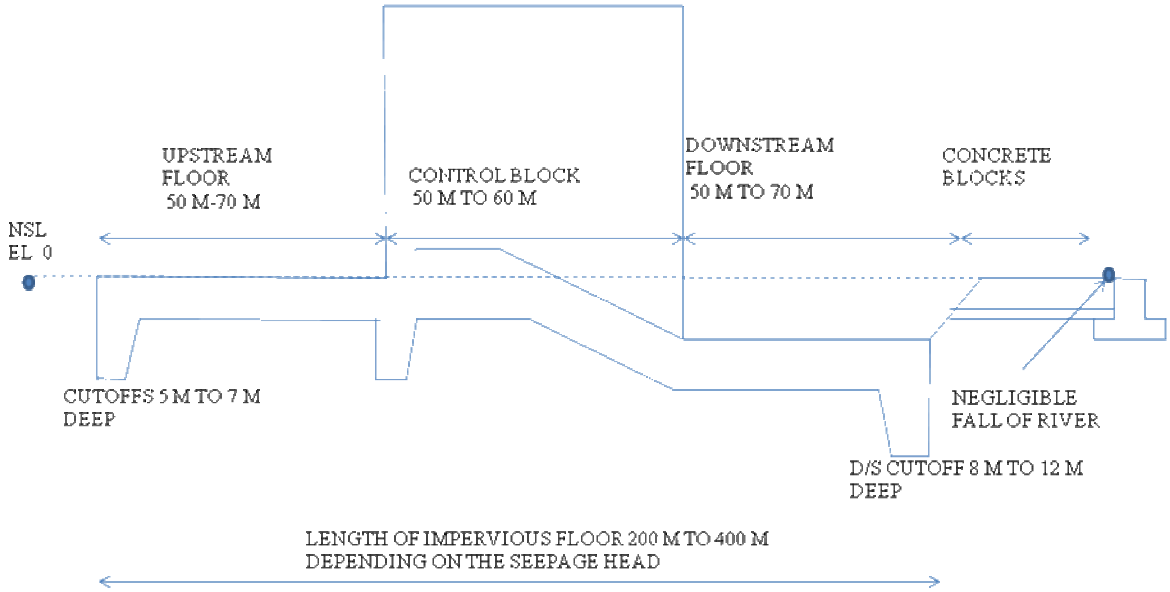

Fig.1 Conventional Stilling Basin (Type- a) with Depressed Floor

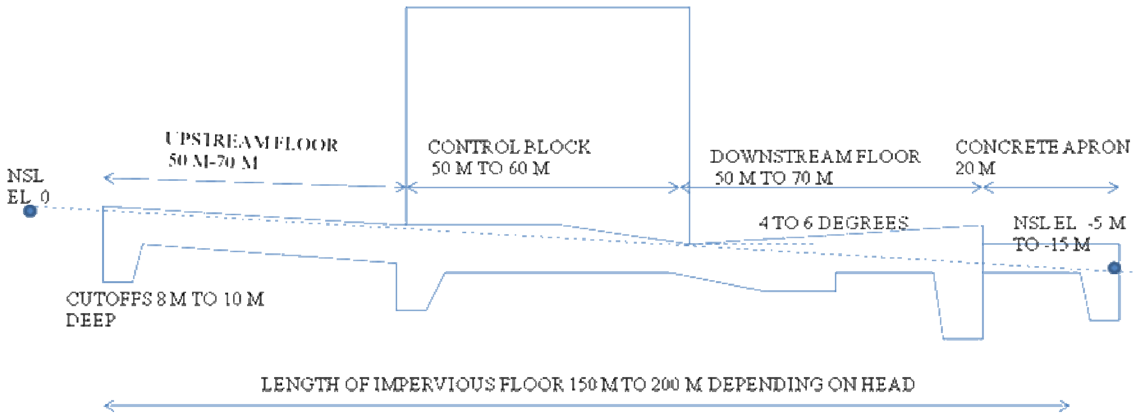

Fig.2: Stilling Basin with Adversely Sloping Basin Floor (Type – b)

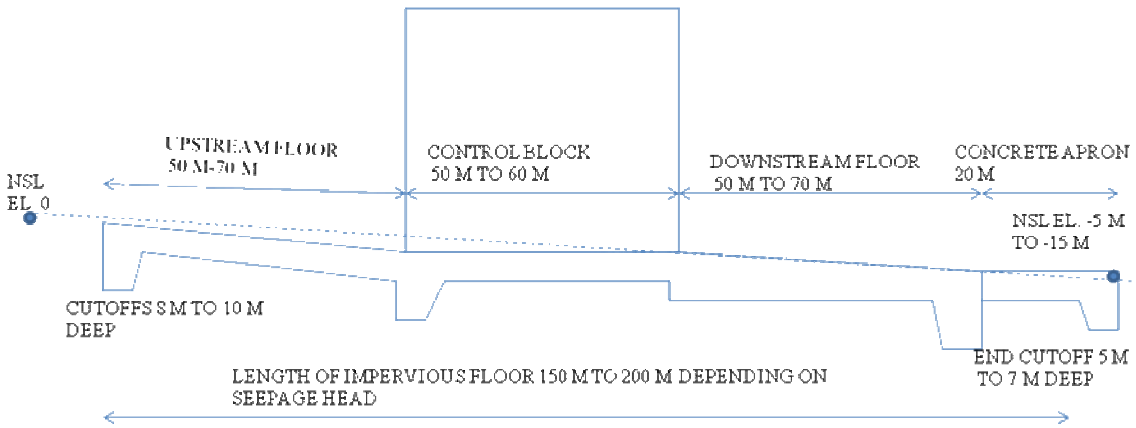

Fig.3: Stilling Basin (Type-d) without Energy Dissipation

Now, in case of flat rivers, the fall of river is negligible in the entire length of diversion structure. The velocities in the river are strictly sub critical. A conventional stilling basin can be adopted as there will be built up of sufficient tail water levels due to subcritical flows. Also, due to presence of higher tail water levels, these stilling basins can be seated at a shallow depth from the river bed level with less excavation.

Conversely, for steep flowing rivers, the fall of river across the diversion structure is in the range of 5m to 10 m. Due to steep slopes, the depth of water in the river is very low thus producing lower tail water levels. Conventional stilling basins, if adopted, requires to be seated deep below the general river bed level demanding greater excavations in bouldery strata which is not feasible from construction point of view. Also, the sub critical velocities in the stilling basin will once again reach the supercritical values downstream due to the steep gradient of the river.

Any unconventional stilling basin, if adopted, on one hand, will boost the tail water level downstream of diversion structure but, on the other hand, will increase the velocities downstream of diversion structure leading to scouring.

Taking into view the above considerations, a diversion structure with no energy dissipation arrangement could be thought of with the downstream floor closely matching with the general river bed level. The velocities of flow will be marginally increased due to the construction of diversion structure as compared to the virgin flows. Technically, the velocities entering the diversion structure should nearly match with the velocities leaving the structure.

d. Downstream Cutoff for Protection against Scour

Lacey's formula popularly applied to calculate the scour depth of rivers in plains is not applicable in bouldery reaches of rivers. Scour depth will be far less than that calculated from those based on the Lacey's formula due to armouring effect of large sized boulders.

A downstream cutoff of 8 m to 10 m shall be considered sufficient with an extra cut-off of 5 m to 7 m depth at the downstream end of the protective concrete apron. Care has to be taken in such a way that the downstream cutoff should not hinder the free flowing of sub surface water.

e. Downstream Protection Works

As per the conventional design practice, interconnected concrete blocks of size 5m x 5m x 2m laid over filter are provided downstream of cutoff after the stilling basin to avoid scour due to residual kinetic energy of flow. However, considering the less perfect energy dissipation arrangement and high velocity flows, it has now been recognized that a single monolith concrete apron with single slope floor from upstream to downstream is more suitable for smooth flow of boulders. A 20 m length of concrete apron having slope same as that of river bed with another cut-off 5 to 7 m deep shall be provided in place of conventional concrete blocks for protection against scour on the downstream side. The concrete apron will have 20 cm size pressure relief holes (duly protected with filter) 2m centre to centre both ways. Beyond the block protection, loose stone protection consisting of large size boulders up to 1m size shall be provided for a length of about 20 m.

The authors have deeply referred all the references listed below but were unable to find the solutions to the problems mentioned in this paper. The researchers should come up with the relevant literatures/findings which suits for designing of such diversion structures. A similar type of diversion structure on boulder strata with no energy dissipation arrangement constructed on River Alaknanda for Vishnuprayag HEP is under operation and is performing hydraulically efficient.

CONCLUSIONS

From the studies presented, following inferences can be made:

1. Khosla's exit gradient theory and Lane's weighted creep theory are not applicable for bouldery strata.
2. Cutoff depth of 8 m to 10 m for a seepage head of 20 to 25 m shall be considered safe to prevent scour since Lacey's scour depth is not applicable for bouldery reaches.
3. The researchers / practicising engineers are suggested to provide more field information and research for the design of diversion structures in bouldery rivers with steep gradient.

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