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Comparison of Labyrinth Weir with Traditional Weir

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***Abstract*—Recent advances in Hydrology, Meteorology and the availability of longer runoff records at prompted the revaluation of some dams and the reservoirs to see if they are safe. This revaluation is has confirmed that some reservoirs are not large enough to supply the demands for water and still hold enough water to Prevent overtopping. To prevent overtopping, some dam will need to have larger capacity spillways or other outlet structure. When a dam is design, the service spillway is usually design to pass the hundred years flood. The emergency spillway is typically designed to pass floods in excess of the hundred year flood. If the service spillway is under design, the emergency spillway will be used more frequently. This is usually not a problem. If the emergency spillway is under design, there can be problem as any excess water beyond the capacity of the emergency spillway will go elsewhere. This excess water may go over the top of the dam. When water flows over the relatively unprotected face of the dam, severe damage or complete dam failure can occur. If dam fails, the loose of life and property can be devastating. To prevent these loses, several alternatives are available. To prevent overtopping, some dam will need to have larger capacity spillways or other outlet structure.**

Keywords- overtopping; spillway; reservoirs

I. INTRODUCTION

The emergency spillway is typically designed to pass floods in excess of the hundred year flood. If the service spillway is under design, the emergency spillway will be used more frequently. This is usually not a problem. If the emergency spillway is under design, there can be problem as any excess water beyond the capacity of the emergency spillway will go elsewhere. This excess water may go over the top of the dam. When water flows over the relatively unprotected face of the dam, severe damage or complete dam failure can occur. One option to increase the capacity of spillways is to lower the crest of spillway and install gates. When the flood water is at the gates, the gates can be opened and the flood can be released. A gated spillway requires the addition of expensive backup equipment and/or a person to open the gates at the correct time. Another option may involve making the existing spillways longer. This option is effective if the site geometry allows the length to be enlarged at the reasonable cost. A third option that can be explored is to raise height of the dam or to allow the maximum water height to encroach higher on the board of the dam. This can be effective if the probable maximum flood can be passed safely with only a little extra rise in surface elevation. A fourth option that is available is to install a fuse plug in the part of the dam. This option allow part of the dam to give way before the entire dam fails. When the fuse ruptures, the rest of the dam may be safe but the damages downstream can be almost as large as if the entire dam failed. A fuse plug is not recommended unless all other option has been explored without success. Another option to increase flow would be to build another emergency spillway. This option may work well in some cases and not well in other. The decision for an extra spillway should be based on existing site condition.

The labyrinth spillway is characterized by a broken axis in plan in order to create a greater length of crest compared to a conventional spillway crest occupying the same lateral space. The broken axis forms a series of interconnected V-shaped weirs each of the V-shapes is termed a cycle. The spillway shown in is a lo-cycle labyrinth spillway. The labyrinth spillway is particularly well-suited for rehabilitation of existing spillways and for providing a large-capacity spillway in a site with restricted width. This due to significant increase in a crest length for a given width. The free- overflow labyrinth spillway can be designed to allow reservoir storage capacity equal to that provided when using a gated spillway, but without increasing the maximum reservoir elevation. This is achieved by the extremely large increase in with a relatively small increase in reservoir stage. The labyrinth spillway hydraulic characteristics are extremely sensitive to approach flow conditions. This requires sitting the crest configuration as far upstream into the reservoir as possible in order to achieve approach flow nearly perpendicular to the axis. Serious consideration of this type of spillway will require verification of the design by a physical model study. Labyrinth weir is simply a linear weir folded in the plan view to form a zigzag in shape. Labyrinth weir is an overflowing weir in plan view so as to increase the total effective length of the crest. It has a longer crest length than linear weir occupying the same width with a longer crest length per foot of width. A labyrinth weir can pass more water than linear weir. This extra length per foot of width can be a big advantage when an existing spillway is upgraded. A labyrinth weir is particularly useful where the overflowing length of a linear weir is restricted due to site specific condition. To prevent overtopping, some dam will need to have larger capacity spillways or other outlet structure.

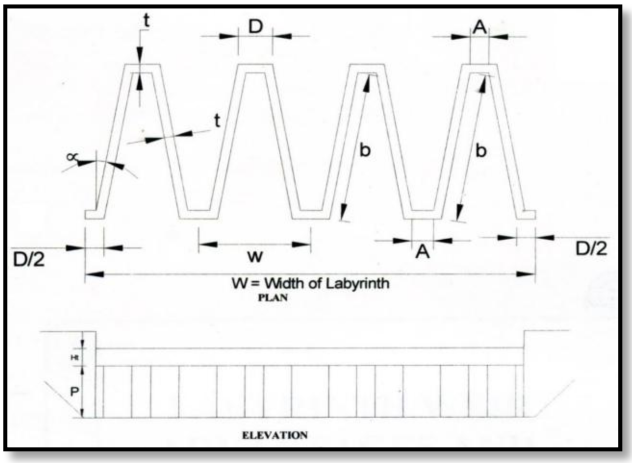

Fig. 1. Layout and details of labyrinth weir

II. LABYRINTH WEIR

The first analysis of the hydraulic performance of the labyrinth weir isattributed to Hay and Taylor (1970) [1]. This work presents a method toevaluate theoretical value of discharge coefficient, and provides both criteriaand procedures for determining the discharge over a labyrinth weir of anycross-section. In their work, they found that the efficiency of a labyrinthcrest for particulate horizontal-plane geometry may be expressed as Q_L/Q_N.

$$\frac{Q_L}{Q_N} = f;\ (\mathbf{h/p,\ Shape})$$

When curve of QL/QN are plotted against H/P for a triangular/trapezoidallabyrinth weir.When the width of one cycle greater than2.5 times the weir height. It can be seen that, as h approaches zero, thedischarge efficiency,QL/QN, approaches the length of magnification ratioR/W. the frequency decreases as operational head increases (with rapiddecreases occurring for the large magnification ratio). This study show thatlabyrinth type crest function efficiency at low surcharges.

Darvas [2] simplified the method of presentation of data of labyrinth weirproposed by Hay and Taylor by eliminating hypothetical liner weir. Heproposed a new design chart by expressing coefficient of discharge asfunction of non-dimensional parameters of length magnification and head to weir ratio. Basic data for the preparation of this chart were obtainedfrom modal tests. These tests are conducted under the following condition

i. Free flow over the weir
ii. 1≤L/W≤8
iii. (α/αmax)≤0.8
iv. W/P≥2 and
v. 0.2≤H/P≤0.6

The weir used in these modal tests was trapezoidal in plan with a horizontalbed. The crest profile was a quarter rounds.

The US Bureau of Reclamation tested quarter-round liner weir and found that it was the most efficient when used with upstream vertical wall. To prepare design charts for a round crest, the difference between the discharge coefficient for sharp and rounded crests was estimated from flumestudies and the discharge coefficient curve of sharp-crested weir modified. The use of the quarter-rounded crest result in slightly higher discharge than sharp crested weir. The result of triangular sharp crested weir for 2≤L/W≤5 are shown in Fig.2. Plotting QL/QN versus Ht/p. these curves were developed using the total head, Ht which includes the measuring head Hm plus velocity head $V^2/2g$.

Hay and Taylor design curve apparently do not include total head and therefore, are not applicable to a reservoir situation without measured head value. This difference in head definition appears to the difference between the Hay and Taylor and Bureau design curves. The design procedure remain same however, the Hm terms should be replace with Ht [3].

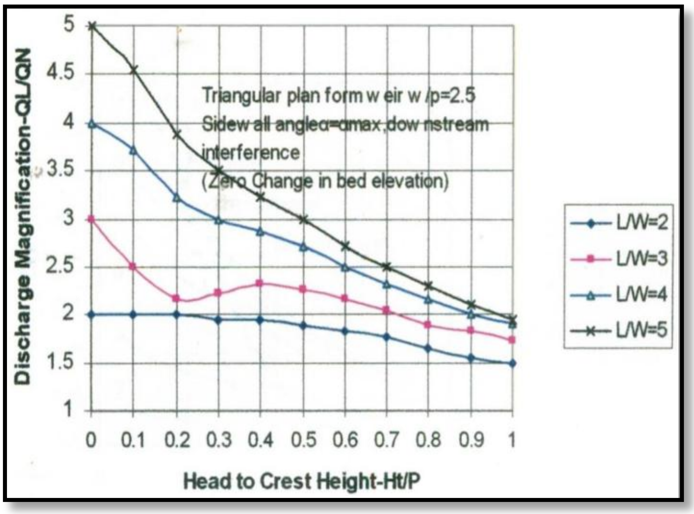

Fig. 2. Bureau design curve

Lux (1984) [4] found that as the flow over a labyrinth weir is three dimensional and therefore not amenable to a mathematical description. Hence he proposed that solution for discharge function can be derived from dimensional analysis and experimental observation. After performance dimensional analysis he developed another discharge coefficient based on the total upstream head. His relationship for the discharge of one cycle is given by

$$Qc = Cw\left(\frac{\frac{w}{p}}{\frac{w}{p}+k}\right)w\sqrt{g}\,Ht^{3/2}$$

In which

K= a shape constant

Ht = the total upstream head

Lux found that k= 0.18 for triangular plan forms and 0.1 for trapezoidal plan forms when a/w was equal to 0.00765, in which a is the half width of the upstream face of the labyrinth weir

For multiple cycle the discharge given by this equation must be multiplied by the number of cycle, n

QL = Qc x n

Clearly Cw will be a function of Ht/P and L/W as well as Ht/P for given polygonal pattern. Result obtained from such tests on sharp-crested labyrinth are presented in Fig. 3.

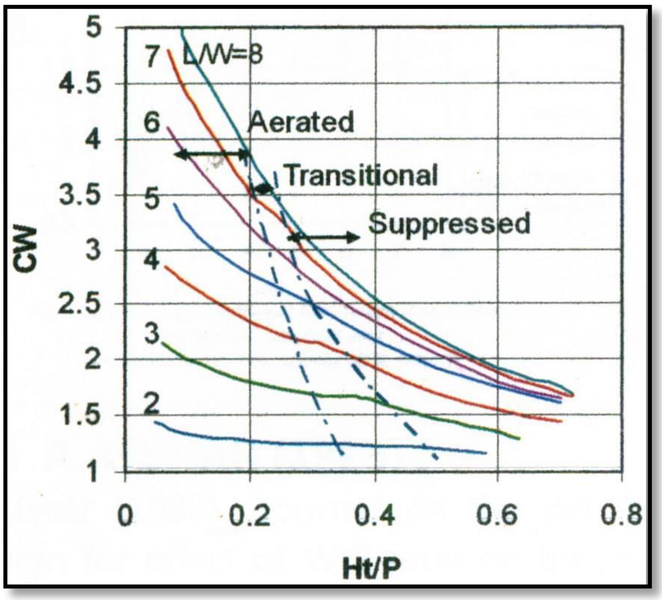

Fig. 3. Design for Quarter Round Crest Trapezoidal Labyrinth Weir [4]

Waldron David Ross (1994) [5] reported that the crest height, thickness, shape and angle or range of angle to build a labyrinth weir. He develop a cost effective method to pass a given flood. He found that the optimal range to design a labyrinth based is between about 6° and 12° for the alpha angle. In this range, the hydraulic characteristics of the labyrinth weir are very similar. If the alpha angle is much less than 6°, than the weir is inefficient due to increased napped interference. If the angle is much larger than 12°, then the weir is not as effective as it takes more width to pass the same amount of water that could be passed with a smaller and usually less expensive weir. The optimal cost shape for heads greater than 0.5 Ht/p is ¼ round. This crest shape is easy to build with only a few special forms needed. This crest shape is hydraulically efficient because it does not exhibit the separation on the leading edge of the weir found in flat-top and sharp-crest weirs. Over the low range of Ht/p value, a 1/2 – round shape is more effective than ¼ round- round shape. At higher Ht/p value, this advantages is negated because the water separates over the high point on the crest.

Tullis et al (1995) [6] carried out extension experimental work on performance of labyrinth weir. They presented crest coefficient curve in simplified way as compared to previous investigators. They proposed a method for designing a labyrinth weir by using the basic equation used for linear weir which would also be applicable to labyrinth weir with modifying in coefficient of dischargeas,

$$Q = 2/3\, Cd\, L \sqrt{2g}\, Ht^{3/2}$$

Where,

Cd = coefficient of discharge, L=effective length of the weir

Ht = total head on crest

Using their experimental data, the value of crest coefficient for full range of variables were obtained and the crest coefficient Cd for a labyrinth weir for α between 6°to 35° have been represented by set of equation. Using their experimental data, the value of crest coefficient for the full of range of variable were obtained and the crest coefficient Cd for a labyrinth weir for α between 6°to 35° have been represented by them by a set of equations

The data were fit with an equation of the form,

$$Cd = A_1 + A_2\left(\frac{H}{P}\right)^1 + A_3\left(\frac{H}{P}\right)^2 + A_4\left(\frac{H}{P}\right)^3 + A_5\left(\frac{H}{P}\right)^4$$

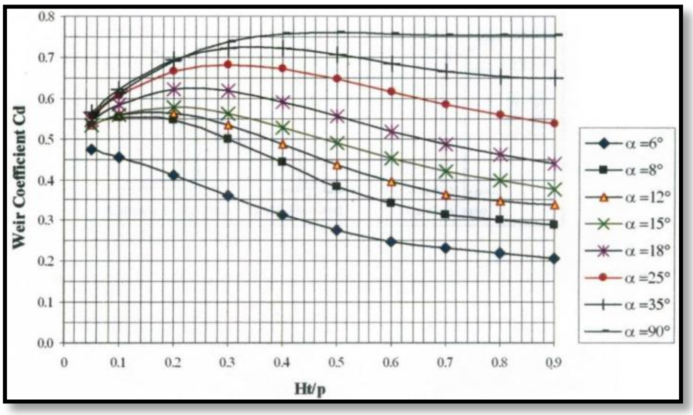

Fig. 4. Crest coefficient for labyrinth spillway

B.P.Tullis, C.M Willmore and J.S.Wolfhope (2005)carried out extensive experimental work on performance of labyrinth weir with a side wall angle 7° to 8°. They presented discharge coefficient data for labyrinth weir half round and quarter-round crest for weir side wall angle 7° to 8°. A third crest shape was tested, which is described as an ogee-type crest (upstream crest radius was 1/3rd the wall thickness and downstream was 2/3rd the wall thickness). They found that using an ogee type crest shape on the a labyrinth weir can increase the weir discharge capacity at low heads (Ht=0.1) by more than 10% for the both the 7° weir, and 8° weir, relative to half round crest shape and by more than 20%, relative to quarter round crest shape.

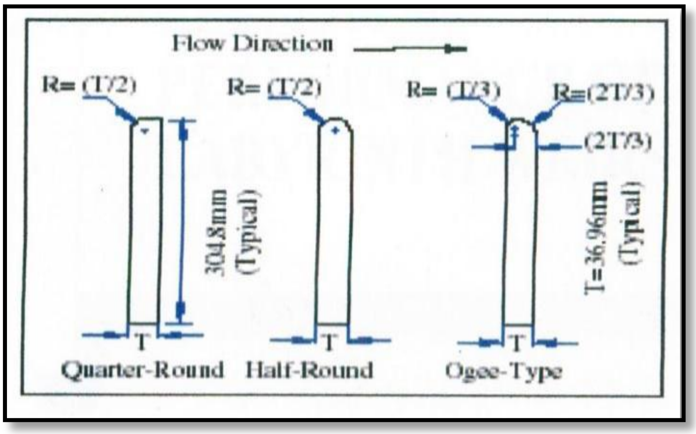

Fig. 5. Discharge Coefficient Data for Labyrinth Weir Half Round, Quarter-Round and Ogee-Type

III. DESIGN PROCEDURE

The following design method is based on the recommendation contained in previous section and uses the charts given by Hay and Taylor.

1. Determine the crest height, p, and the channel width, w, from the site conditions.

2. Define the maximum allowable head on the weir, h max to satisfy the operational requirements.

3. Define the maximum discharge (QL)max to be accommodated at the maximum operating head from hydrographic surveys, etc.

4. Using p and w. determine the maximum discharge (QN) max that could be obtained from a corresponding sharp create linear weir operating under the head h max.

5. From the previous steps, calculate the required flow magnification of the labyrinth weir (QL/QN) which corresponding to (h/p) max.

6. Choose between the triangular or trapezoidal plan-forms.

7. Adopt the recommended design parameter i.e. vertical aspect ratio w/p>2, and no apron in the design.

8. Determine from the site conditions whether any difference in the elevation exists between the channel beds upstream and downstream of the weir. If there is a difference in the bed elevation, and this exceeds the maximum head on the weir, no downstream interference to the flow will occur and the corresponding performance on the design charts should be used.

9. Plot the design point, (h/p, QL/QN) max on the appropriate design charts depending on whether a trapezoidal or triangular plan from adopted. Interpolate between the curves to determine the length magnification of sharp crested labyrinth weir.

10. Choose a crest section for the weir and determine from experimentaldata the ratio of the crest coefficient of that section to that of sharp crest at the value of (h/p)max.

11. Divide the length magnification of sharp-crested labyrinth weir by the ratio at crest coefficient of determined in step 10.The resulting value is the required length magnification of the actual labyrinth weir.

12. The weir design parameter have been determined and it is a simple matter to calculate the actual dimensions of the weir. Note that the number of the weir cycle is W/w, and that w/p should be modified such that W/w is the integer or integer 1/2. The following steps allow the prediction of the weir performance over the full range of operation.

13. Select the No. of value of h/p in the range 0< h/p< (h/p) max.

14. For each value of h/p determine the ratio of the crest coefficient to the sharp crest coefficient, f. By multiplying the length magnification of the weir by each crest coefficient ratio determine the magnification of the equivalent sharp crested labyrinth weir, (QL/QN) equivalent corresponding to each chosen value of h/p.

15. For each of h/p, determine the flow magnification of equivalent sharp crested labyrinth weir (QL/QN) equivalent by interpolation from the design charts.

16. The actual discharge over the labyrinth weir may be found by multiplying the flow magnification of the equivalent sharp crested labyrinth weir by the corresponding linear weir discharge, QN. Which may be calculated from standard sharp crested weir formula.

17. The ratio f of crest coefficient to that of sharp crest is known for each values of h/p (the ratio may vary with h/p). Dividing the equivalent sharp-crested labyrinth weir flow magnification (QL/QN) equivalent by these ratios gives the flow magnification of actual labyrinth weir, QL/QNs.

IV. LAYOUT PLAN FOR HATOLA TANK PROJECT BARSHITAKLI

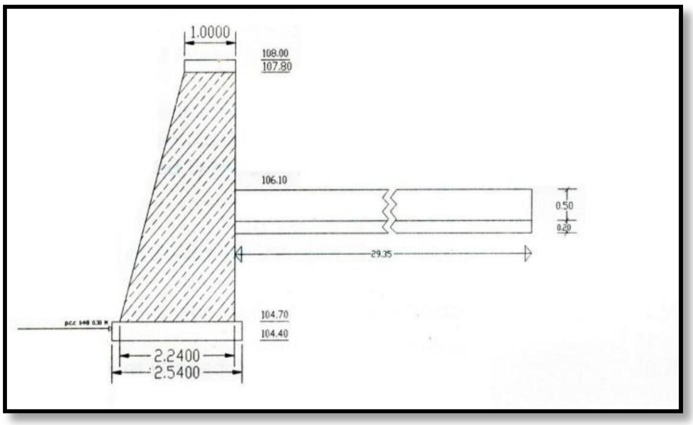

Fig. 6. Section of Labyrinth Weir

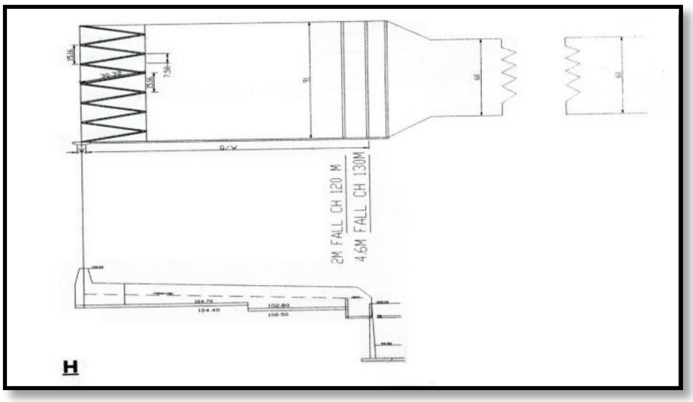

Fig. 7. Plan of Labyrinth Weir

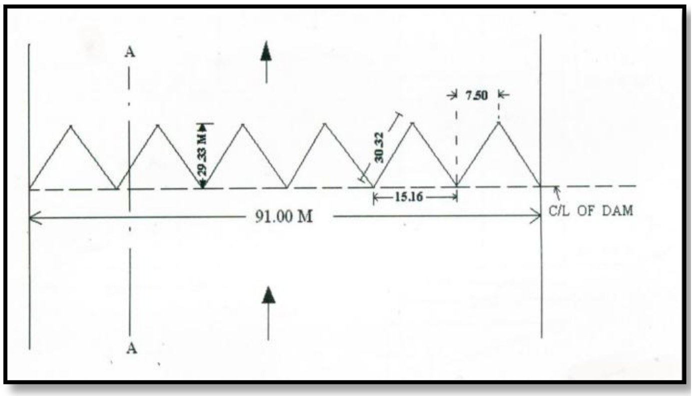

Fig. 8.Design of Labyrinth Weir

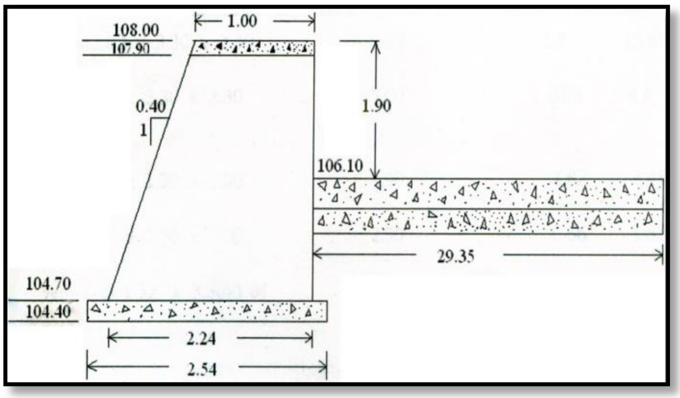

Fig. 9. Design of Labyrinth Weir

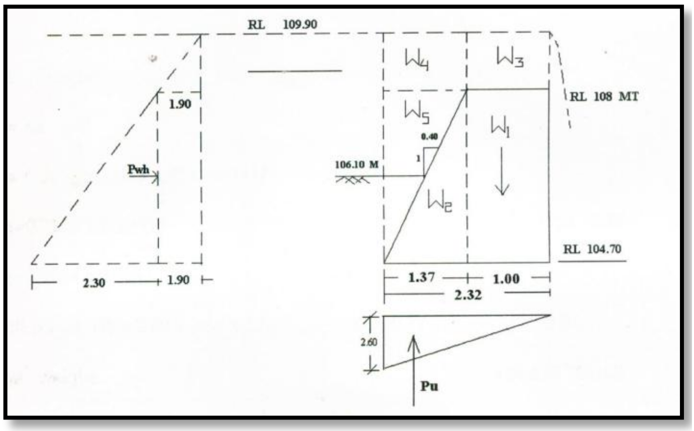

Fig. 10. Stability Calculation for Waste Weir Bar of Labyrinth

V. ACTUAL SITE PHOTOS

Name of the Project: Hatola tank project

Location: Barshitakli (35km from Akola)

Net catchment area = 9.5 sq.miles.

Net length of straight weir = 91mtr.

Effective length of labyrinth weir = 364 mtr.

Magnification ratio (L/W)= 4

Fig. 11. Side View of Labyrinth Weir

Fig. 12. Front View of Labyrinth Weir

Fig. 13.Top View of Labyrinth Weir

Fig. 14.Side View of Labyrinth Weir

VI. CONCLUSION

Based on the parameters of performance of labyrinth weir and comparative study the following conclusions have drawn:-

1. To maintain the effectiveness review of labyrinth weir the value of ratio h/p should be less than 0.9.

2. With a h/p of 0.7 and sidewall angle of 14.47, the discharge coefficient is 0.409, the magnification is 4 and discharge coefficient have the straight weir is 0.75, this fives an efficiency canal 2.58. This means that the labyrinth can pass a little more than 2.25 times the flows of a given head that straight weir.

3. Labyrinth weir enhances the discharge capacity of the spillway. This helps to prevent abnormal rise in the reservoir water level during peak floods, thereby ensuring the safety of dam.

4. Labyrinth weir will be most suitable on the sites where the length of spillway is restricted due to various reasons.

5. Further study if possible shall be on the following points:

A. The economical layout

B. E.D.A arrangement

C. Cost comparison of Labyrinth weir VS normal spillway

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