# Optimizing Location of Cutoffs to Improve Safety and Economy of Hydropower Projects

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**Abstract:** Large numbers of perennial rivers flowing through steep gradient has made Nepal an ideal place for hydropower development. Development of hydropower project in most economical way possible is the first prerequisite to get maximum benefit from harnessing water resources. The maximum benefit can be achieved only through optimal design of the project. Each project component must be designed considering the required level of factor of safety, performance standards of each component and economy. On this backdrop, this paper intends to optimize the location of cutoffs in headworks to get maximum benefits from use of it in terms of safety and economy.

Improper placement of cutoff not only reduces the factor of safety against piping but also curtails the project benefits due to excessive seepage flow. Piping (internal erosion of soil particles under structure) is associated with high exit gradient. It threatens the structural stability and ultimately leads to failure of structure while as excessive seepage flow limits the availability of flow for power generation and reduces the project benefits. So, the optimal design of headworks is an attempt to identify the best location of cutoff to control seepage flow and reduce exit gradient. Five different cases representing different location of cutoff were analyzed and their roles in controlling seepage flow and reducing exit gradient was evaluated to optimize the cutoff location. 2D Finite Element Method (FEM) was used for the seepage analysis. The analysis showed that cutoffs are essential to control seepage flow when dam/weir is founded in pervious soil. However, the best location to place cutoff must be adroitly identified to reap maximum benefit from use of cutoff. The analysis reveals that the role of central cutoff in controlling seepage flow and reducing exit gradient is very limited. Likewise, the u/s cutoff has minimum effect in reducing exit gradient but the d/s cutoff seemed very effective in reducing exit gradient resulting increased factor of safety against piping. Hence, this paper concludes that the d/s end is the optimal location to place cutoff to improve safety and economy of the project. In addition, the use of both u/s and d/s cutoffs extend positive roles both in controlling seepage flow and reducing exit gradient. However, in author's opinion the construction cost of two cutoffs must be compared with benefit added by use of two cutoffs over use of single d/s cutoff.

**Keywords:** Hydropower, water resources, cutoffs, safety and economy

## Introduction

Nepal is blessed with huge water resources. Moreover, it is an ideal place for hydropower development supported by favorable topography and perennial rivers. Nepal can boost up its national economy by harnessing its humongous water resources potential through hydropower development in most economical way. One of the most important factors requiring keen consideration in water resource harnessing is proper design of each hydropower components such as headworks, waterways, surge dissipaters and p owerhouse etc. Each components of project must be designed in optimal way ensuring adequate factor of safety, complying required performance standards of each component and maintaining economy of the project. This paper illustrates the findings of study carried out to decide best location of cutoffs in headworks of hydropower projects to maintain required factor of safety and project economy.

Most of the weirs used in hydropower projects in Nepal are constructed on pervious foundation. Hence, an in-depth knowledge on seepage flow phenomenon through the pervious foundation is first prerequisite to design weir structure in optimal way to secure required safety in economical way. Piping (Internal erosion of soil particles) under the weir and floatation of weir itself are the issues related to seepage flow which threatens the structural stability of the weir. On the other hand, excessive seepage flow through weir foundation reduces the availability of flow for power generation and ultimately curtails the project benefit. Different preventive measures to reduce seepage flow and to control piping are applied in many projects in Nepal. However, their appropriateness and performances of applied measures are rarely evaluated. Hence, this paper intends to evaluate performances of various cutoffs and their combinations used in different locations of weir and suggest the best location in terms of safety and project economy.

## Methodology

Two dimensional finite element methods were adopted to analyze seepage flow through the weir foundation. A model with selected geometry and assumed hydraulic parameters was prepared and computation was carried out for five different cases that are standing in common practices.

A broad crested weir made up of concrete material was selected for the seepage flow analysis through its soil foundation. The crest level of weir is 8 m above the foundation level. The u/s face of weir is assumed to be vertical whereas d/s face slope is considered to be 2:1 (H:

V). The total base width of weir is 14.0 m. A definition figure of the problem is presented below:

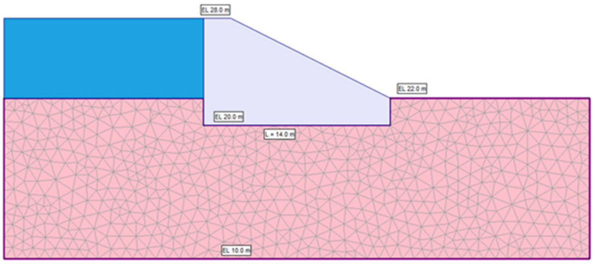


Figure 1: Definition sketch

The depth of water in u/s side is 6.0 m whereas no tail water is considered in d/s side. The hydraulic conductivity of weir foundation is assumed to be 1E-5 m/s. It is also assumed that the bed rock is encountered at a depth of 12.0 m from u/s floor.

The foundation soil is expected to be saturated, homogeneous and isotropic.

## Computation

After assigning above said input parameters into the 2D model, seepage computation was performed for five different cases which are discussed below. The amount of seepage flow and exit gradient are evaluated for each case.

### *Case A (Base case): without any cutoffs*

This is the first case and assumed as base case with no cutoffs. The flow nets computed by Finite Element Method (FEM) are presented below.

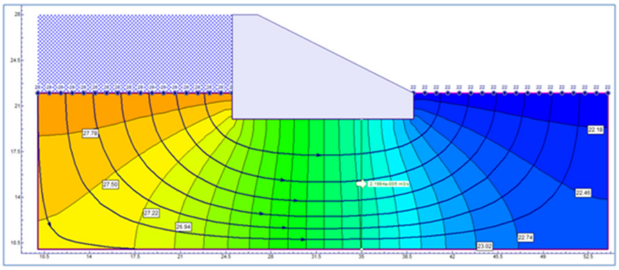

Figure 2: Seepage flow net with no cutoffs

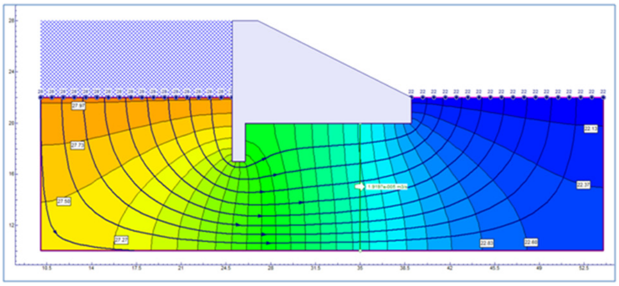

Figure 3: Seepage flow net with u/s cutoff

### *Case B: with u/s cutoff*

Second case was analyzed with introduction of u/s cutoff. The concrete cutoff of 1.0 m thickness and 3.0 m deep was considered at u/s face of the weir while other parameters were kept same as base case. The flow net computed for case B is presented below:

### *Case C: with d/s cutoff*

Case C comprised of cutoff located at d/s end of the weir. For the comparison purpose the dimension of d/s cutoff was assigned similar to that of u/s cutoff i.e. 1.0 m thick and 3.0 m deep. The flow net computed for case C is presented below:

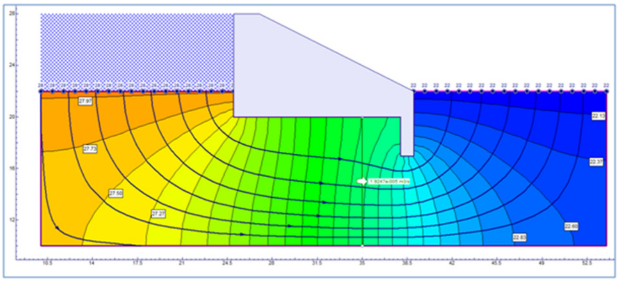

Figure 4: Seepage flow net with d/s cutoff

### *Case D: with central cutoff*

Some small hydropower project has been designed with small weir with the provision of only central cutoff. The effectiveness of such a cutoff in reducing seepage flow and exit gradient was analyzed in case D. The thickness and depth of cutoff were kept same as u/s and d/s cutoffs. The flow net computed for case D is presented below:

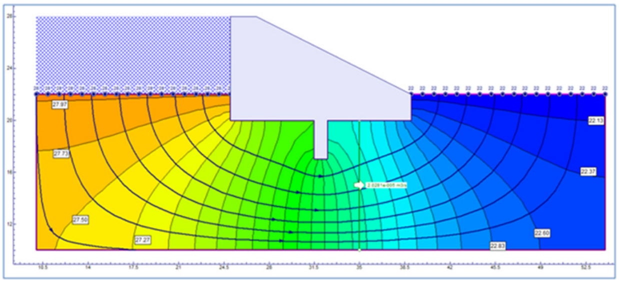

Figure 5: Seepage flow net with central cutoff

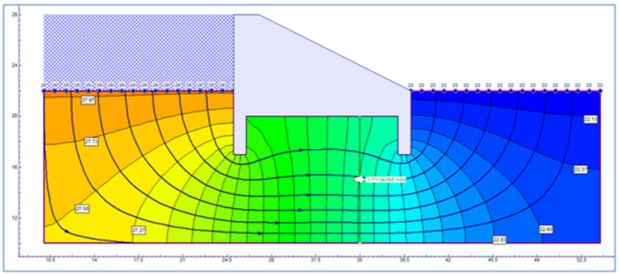

Figure 6: Seepage flow net with both u/s and d/s cutoffs

### *Case E: with u/s and d/s cutoff*

Provision of both u/s and d/s cutoffs are common in most of the headworks of hydropower projects. Case E evaluates the performance of cutoff provided in both u/s and d/s end. The dimension of both u/s and d/s cutoffs were kept same in this analysis. The flow net computed for case E is presented below:

### *Exit gradient*

Exit gradient is the prime factor to cause piping under the weir. The exit gradient must never be higher than critical exit gradient. In addition, designer commonly adopts some factor of safety while deciding design value of safe exit gradient.

The critical exit gradient (ic) can be computed analytically with the following formula:

$$ic = \frac{(rs-rw)}{rw}$$

Where,

rs = unit weight of saturated soil

rw : unit weight of water

For rs = 20 $KN/m^3$ and rw = 10 $KN/m^3$, the critical exit gradient is found to be 1.

Similarly, the factor of safety (FS) is determined by the following formula:

F.S. = Factor of safety for exit gradient for each case was calculated using above formula and the factor of safety greater than 4.0 was considered to be safe design.

## Results and discussions

2D Finite element model was run with different five cases. The seepage flow and exit gradient was computed for each case. Similarly, the corresponding factor of safety against piping was calculated analytically. The summary of results is presented in following table:

Table 1: Performance results of different cutoffs

| Cases | Seepage flow rate, $m^3/s$ | % reduction | Exit gradient | Factor of safety |
|---|---|---|---|---|
| Case A: With no cutoffs (Base case) | 2.19E-05 | - | 0.35 | 2.9 |
| Case B: With U/S cutoffs | 1.92E-05 | 11.37 | 0.30 | 3.3 |
| Case C: With D/S cutoffs | 1.92E-05 | 11.37 | 0.21 | 4.8 |
| Case D: With Central Cutoffs | 2.03E-05 | 7.40 | 0.30 | 3.3 |
| Case E: With both U/S and D/S cutoffs | 1.71E-05 | 21.92 | 0.18 | 5.6 |

Result shows that the maximum seepage flow was observed in case A: with no cutoffs. In addition, this case exhibits factor of safety less than 4.0 and considered as unsafe design. An interesting result was found in case B: with u/s cutoff and case C: with d/s cutoff, as both cases compute similar amount of seepage flow but the exit gradients are so different. The provision of d/s cutoff is seemed more effective in reducing exit gradient leading to safe design as factor of safety was found to be 4.8. On the other hand, the role of central cutoff (case D) was not found so effective both in reducing seepage flow and exit gradient. The computed factor of safety was found less than 4.0 hence led to unsafe design. Further, the analysis shows that the minimum amount of seepage flow and highest factor of safety was attained in case E: with both u/s and d/s cutoffs. However, in author's opinion the cost for construction of two cutoffs should be compared with benefits gained by increased factor of safety and reduced seepage flow quintiles due to application of two cutoffs.

## Conclusion

A thorough knowledge of seepage flow phenomenon through the pervious foundation is very essential while designing headworks of hydropower projects. Improper design of cutoffs not only leads to structural failure but also increases seepage flow and reduce amount of water availability for power generation which ultimately affects the project economy. Five different cases with varying location of cutoffs were analyzed to optimize the location of cutoffs in headworks. The analysis shows that the u/s and central cutoffs are not so effective in reducing exit gradient and controlling seepage flow. On the other hand, the d/s cutoff plays very effective role in reducing exit gradient thus increase the factor of safety against piping in most economical way. Therefore, it can be concluded that the cutoff must be provided at d/s end of weir to improve factor of safety against piping. Likewise, provision of both u/s and d/s cutoffs are effective both in reducing seepage flow and increasing factor of safety. However, the construction cost of two cutoffs must be taken into account while deciding to go for two cutoffs.

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