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EVALUATION OF DIFFERENT SEEPAGE CONTROL MEASURES FOR A PROPOSED "GOLEN GOL" WEIR IN PAKISTAN

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Abstract

The Golen Gol weir foundation is pervious and there is a worry of considerable seepage. To control seepage, a scaled model of the weir section and its foundation was developed in SEEP/W and analysed for seepage quantity. The analysis was divided into several trials. In one trial, a continuous pervious foundation of weir without any seepage control measure was modelled and analysed for seepage quantity. This was used as a base (reference) case for comparison. In other trails, different seepage control measures, such as, downstream filter, upstream blanket, cut-off (upstream, mid, downstream) and combination of upstream blanket and cut-off, were used. Different lengths of upstream blanket and depths of cut-off were tried. In each trial, twenty different material regions were defined and hydraulic conductivity function (K-ratio = K_y/K_x) was defined for each region. Also, a total head of 2052m, on the upstream side, was selected as one of the boundary condition for the study problem. The results of the analysis revealed that the upstream blanket of length 30m and combination of downstream and upstream blankets (each 10m deep) showed nearly equal reduction in seepage quantity. However, the exit gradient for blanket was found more on safe side and also its cost of construction was estimated less than the cost of the cut-offs.

Keywords: Weir, Foundation, Seepage, Cut-off, Filter, Blanket.

1. Introduction

Weir is a solid obstruction placed across a river. Its main function is to raise the water level, so that, water can be diverted by canal or conduit, for the purpose of irrigation, power generation, and flood control, and also for domestic and industrial uses. Weirs may either be founded on an impervious solid rock foundation or on a pervious foundation. In case of pervious foundation, there is great seepage of water beneath it. Seepage is defined as the flow of a fluid, usually water through a soil, under a hydraulic gradient. All hydraulic structures are subjected to some seepage through its foundation. The force or pressure behind the seeping water can create new or enlarge existing seepage pathways. Seepage of water is one of the major problems as it affects hydraulic structures. Seepage water flowing below the foundation of hydraulic structures founded on permeable soils exerts pressure on the structure and tends to wash away soil under it. Excessive uplift pressure and piping are often the main cause of damage which leads to failure of the structure. Seepage through earth structure causes several problems and damage. Problems such as soil erosion and cracking were observed in Raishahi City Protection Embankment, Bangladesh, due to seepage developed during rainy seasons (Md. Minhaj and Younas, 2004). Because of these potential problems associated with seepage, it is essential to control seepage in both velocity and quantity for safe operation of hydraulic structure. The operation of preventing seepage from weirs after construction is difficult and proves quite expensive. Therefore, some precautionary and controlling measures must be considered prior to construction. By proper evaluation, analysis and design followed by proper construction, the seepage problems can be avoided.

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2. Problem Statement

Energy is crucial for development of a country. The fast growing energy requirements in Pakistan need to be met in order to achieve full economic and social development. Currently, most of the energy demands are being met through thermal power projects, which need fossil fuel. As the fossil fuel is mostly imported through foreign exchange and thus their power generation proves costly for general public and industrial use. The government of Pakistan is focusing on the development of indigenous domestic hydropower resources. Pakistan has huge hydropower generation potential which needs to be exploited on long-term basis for provision of power at much lower costs. Therefore, keeping in view the vital role of hydropower in energy sector, WAPDA in Pakistan has initiated preparation of feasibility studies for construction of hydropower projects in various parts of the country, where suitable sites are available. Golen Gol Hydropower Project, in district Chitral of Pakistan, is one among the proposed sites.

3. Seepage Control Measures

The main objective in the design of a new hydraulic structure, like, weir, is to provide adequate measure to control seepage and erosion. Cut-off trenches, cut-off walls, combination of trenches and walls or even upstream impervious blankets are commonly used seepage control measures adopted with foundation of unconsolidated permeable materials. The closing of seems, joints and other openings in the bedrock is usually necessary for better seepage control (Fell et al., 2005). It is impracticable to stop all seepage under a weir. Water will inevitably escape somewhere in the vicinity of the downstream toe and if the foundation material on the downstream side consists of fine sands, silts or clays, then they may be carried away by the seepage water escaping under pressure. An inverted filter constructed of selected materials ranging from fine to coarse from bottom to top, may be provided to eliminate this problem. The filter permits necessary passage of water but prevents the displacement of fine soil particles (US Department of the Interior Bureau of Reclamation, 1990). Sedghi-Asl et al. (2012) carried out an experimental study on coastal Dike, using sheet pile and impermeable blanket as seepage control measures. They used four different depths of the sheet pile and four different lengths of the blanket. The result of their study indicated that the integrated application of two seepage control measures had more significant effect on reduction of uplift pressure. The study also showed that the effectiveness of the seepage control measures depends solely on the thickness of the foundation material, penetration depth of the sheet pile and the maximum upstream water level. Zhang et al. (2012) used finite element simulation to illustrate possible engineering problems caused by seepage. They suggested seepage treatment measures, such as, impervious wall and blanket, pervious cover in the backland and release wall and ditch and demonstrated how the various seepage control measures can improve the stability of the foundation. Seepage flow through the foundation, consisting of rock or soil and also through the body of a geotechnical and hydraulic structures, has a great influence on their stabilities and performance. Seepage control is a critical and the most significant issue in the geotechnical engineering field. Chen et al. (2010) examined physical mechanisms associated with various measures for seepage control in geotechnical engineering. Based upon their role in the mathematical models of seepage flow, these mechanisms are classified into four types: (i) control by couple processes, (ii) control by initial states, (iii) control by boundary conditions, and, (iv) control by hydraulic properties. The seepage control effects of each mechanism are demonstrated by systematically illustrating examples in nuclear waste disposal, dam engineering and underground engineering. A procedure is suggested by them for performance assessment and optimisation design of a seepage control system in geotechnical engineering, which would serve as a cost effective guidance on control of seepage flow in various engineering practices.

The quantity of seepage under the foundation of most hydraulic structures is of great significance to dam engineers and designers since it plays an essential part in the dam design and safety. Flow nets and the method of fragments have long been used for estimating seepage under hydraulic structures. Many numerical models have been developed that provide seepage estimates by making use of the finite difference and the finite element methods. Yacoub-Najjar and Naouss (2004) used finite element method for estimating seepage and exit gradient under embedded dams with single sheet piles under laid by heterogeneous media. They analysed numerical models and developed different sets of design charts which can be efficiently used for finding seepage and exit gradient under the aforementioned structures.

Edwin et al. (2010) used multiple methods for controlling reservoir seepage. They studied Miller reservoir and dam embankment, consisting of three different dam sections for which the seepage barrier for the dam foundation had a combination of a soil bentonite, cut-off wall and core trench. The clay core of the embankment was connected by four different ways with the different seepage control measures. To evaluate seepage problems and to find its treatment measures, the properties of soil at the site of Chapar-Abad Dam in Iran were investigated. The investigation consisted of a study of the joint systems of rock units, the use of numerical analysis to simulate water flow in the ground and by conducting *in-situ* tests to estimate the permeability values. Owing to cost, feasibility and safety factor, the installation of ground curtain is suggested as seepage controlling measures for the dam (Uromeihy and Barzegari, 2007). Seepage through earth structure causes several problems and damage. Problems, such as, soil erosion, cracking, etc., were observed in Raishahi City Protection Embankment, Bangladesh, due seepage developed during rainy seasons (Md. Minhaj and Younas, 2004).

The need for seepage control will depend on the quantity, content and location of the seepage. Reducing the quantity of seepage that occurs after construction is difficult and expensive. Typical methods, using to control the quantity of seepage, are grouting or installation of an upstream blanket. Controlling the content of the seepage or preventing seepage flow from removing soil particles is extremely important. Modern design practice incorporates this control into the dam design through the use of cut-offs, internal filters, and adequate drainage provisions. Weep holes and relief drains can be installed to relieve water pressure or to drain seepage from behind or beneath concrete structures (New York State Department of Environmental Conservation, 2012). To control, collect and safely discharge the collected fluids, often seepage protection elements within a dam or impoundment in the form of geotextiles, natural filters and drains are considered in the design stage (Richard and William, 1985).

All embankment dams are subject to some seepage. If seepage becomes excessive and uncontrolled, then it adversely affects the stability of the structure, due to development of excessive internal pore water pressures or by piping. Therefore, seepage should be effectively controlled to safe guard the structure. Some of the protective control measures, such as, relief wells, weighted graded filters, horizontal drains or chimney drains prevent seepage forces from endangering the stability of the downstream slope. Filters and transition zones designed to prevent movement of soil particles could clog drains or result in piping. Drainage blankets, chimney drains and toe drains are designed to ensure that they control and safely discharge seepage for all conditions. The design of the above features must also provide sufficient flow capacity to safely control seepage through potential cracks in the embankment impervious zone. Contacts of seepage control features with the foundation, abutments and embedded structures are designed to prevent the occurrence of piping and/or hydrofracturing of embankment and/or foundation materials. If conduits or pipes exist through the embankment, they should be inspected to ensure that they are functional or have been properly sealed. Measures, such as, compaction, seepage collars, placement of special materials, or other similar features may be used to prevent internal erosion due to seepage. (Embankment Dams, 1991).

4. Experimental Programme

4.1 Methodology

The Geo-Slope and Seep/W methods were used to model the fluid flow and pour water pressure distribution within the porous materials (soil and rock) on the weir site. The main features of this model are: a scale of 700m horizontal and 350m vertical was adopted so that an initial working area 296.93mm wide and 210.06mm high was specified for the weir. Twenty four different material regions were defined in this model and hydraulic conductivity function (K-ratio = K_y/K_x) was defined for each regions. The

K-values were obtained by performing constant head permeability tests for weir foundation. Steady state analysis was adopted and two boundary conditions were specified. One boundary condition was set by selecting a total head of 2052m on the upstream side. The other boundary condition was set in terms of total flux (Q) with potential seepage face review along the outer boundaries of the downstream filter. The weir model is shown in Fig. 1.

The model was analysed for seepage with different seepage control measures. This was done in several trials as follows:

Trial 1: In this phase, a continuous pervious foundation of weir without any seepage control measure was modelled and analysed for seepage quantity. This was used as a base (reference) case for comparison.

Trial 2: In this phase, the weir with downstream filter as a seepage control measure was modelled and analysed.

Trial 3: In this phase, the weir foundation with downstream cut-off as seepage control measures was modelled and analysed. Two lengths (depths) of the cut-off of 5m and 10m were analysed separately.

Trial 4: In this phase, the weir with downstream and mid cut-off was analysed. In one combination, 10m length of downstream and 5m length of mid cut-off were taken while in the second combination, each cut-off was taken as 10m deep.

Trial 5: In this phase, the weir with downstream and upstream cut-off was analysed for seepage. Each cut-off was of 10m length.

Trial 6: In this trial, the weir with mid cut-off and upstream cut-off, each 10m deep was analysed.

Trial 7: In this phase, the weir with downstream, mid and upstream cut-off as seepage control measure was analysed for seepage quantity. Each of the downstream and mid cut-off was taken as 10m deep while the up-stream cut-off was taken as 5m and 10m deep.

Trial 8: In this trial, the weir with an impervious up-stream blanket as a seepage control measure was analysed for seepage quantity. Several lengths of the blanket, such as, 20, 25, 30 and 35m lengths, were checked separately, while the thickness of the blanket was kept constant as 0.5m.

Trial 9: In this trial, the weir with all the three cut-off (downstream, mid and upstream each of 10m length) in combination of an upstream blanket as a seepage control measure was analysed. Depending upon the length of the blanket, different combinations of the two seepage control measures were tried. Lengths of the blanket were taken as 20, 25, 30 and 35m, while the depth of the cut-offs were fixed (10m) in each combination.

After seepage analysis, exit gradient study and cost analysis were carried out for two effective cases so that they may be compared.

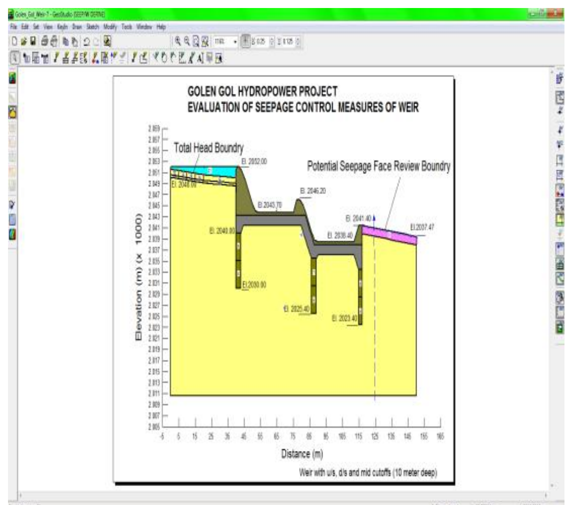

Fig. 1. Weir Model

5. Results and Discussion

The scaled model of the weir section and its foundation alongwith different seepage control measures, developed in the SEEP/W, was analysed for seepage quantity. Flow nets were drawn for different cases. Flow nets for some cases are shown in Figs. 2 to 9. The quantity of seepage found in each trial is given in Table 1, where these are compared with the seepage quantity for base case.

Fig. 2 shows flow net alongwith seepage quantity for base case, where no seepage control measure was provided to the weir. The various flux sections of the flow net reveal that excessive water is being discharged through the foundation material.

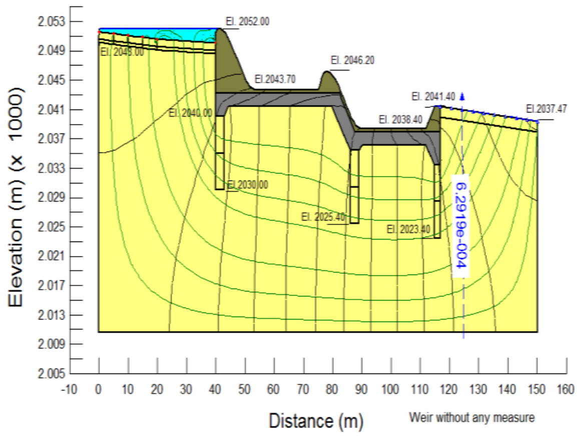

Fig. 2. Flow net for weir without any seepage control measure

Fig. 3 shows that seepage is reduced to some extent by providing the cut-offs.

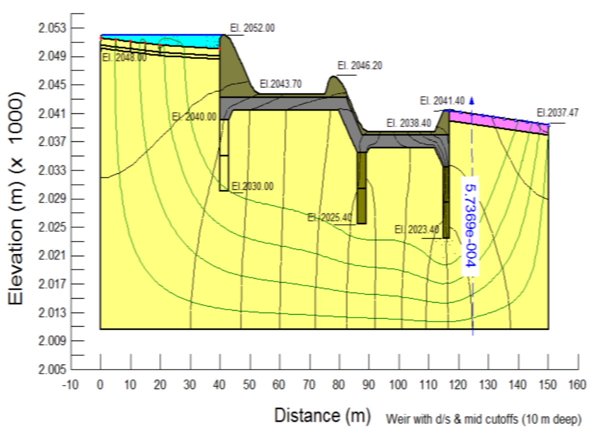

Fig 3. Flow net for weir with downstream and mid cut-offs

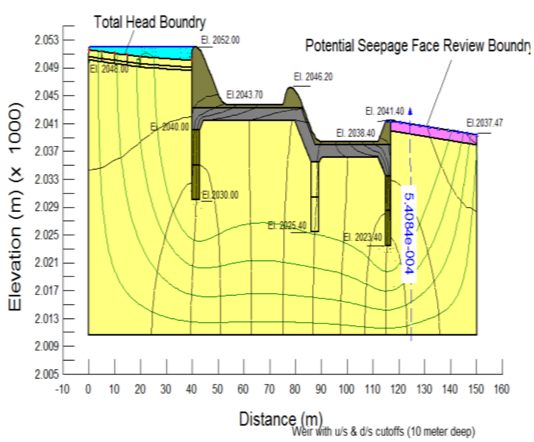

Fig. 4. Flow net for weir with downstream and upstream cut-offs

Fig. 4 shows that seepages are relatively reduced, using downstream and upstream cut-offs as seepage control measures.

Fig. 5 gives flow net for weir with cut-offs (D/S. Mid and U/S). As the cut-offs block the seepage discharge through the highly pervious soil of the weir foundation and thus causes considerable reduction in seepage quantity through the weir foundation.

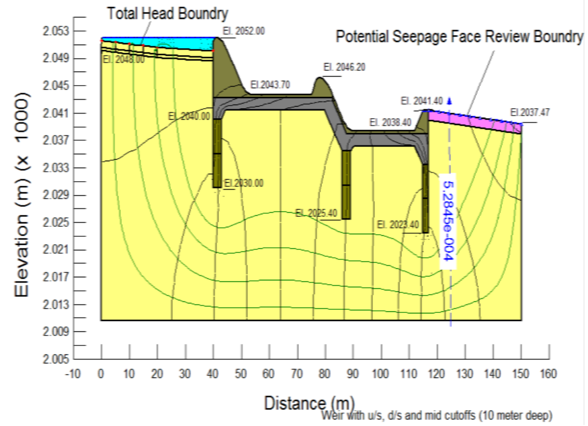

Fig. 5. Flow net for weir with downstream, mid and upstream cut-offs

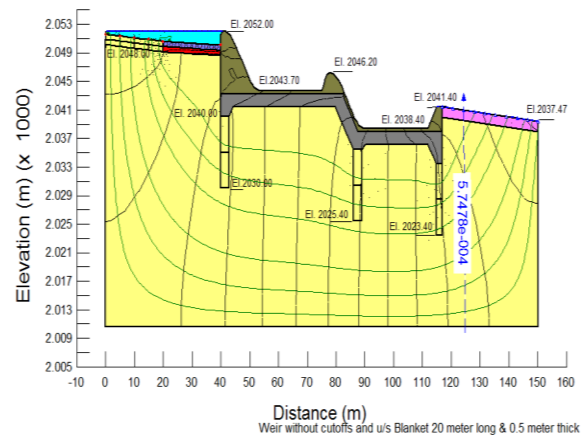

Fig. 6. Flow net for weir with upstream blanket (20m long).

In order to provide the tortuous path for seepage water, an upstream impervious blanket was provided with cut-offs to estimate the seepage reduction through the foundation of Golen Gol weir. Figs. 6 and 7 show the flow nets for the weir with an upstream blanket of 20m and 30m respectively. The blanket provides tortuous path for seepage water and thus causes reduction in the seepage. However, this reduction is function of the blanket length.

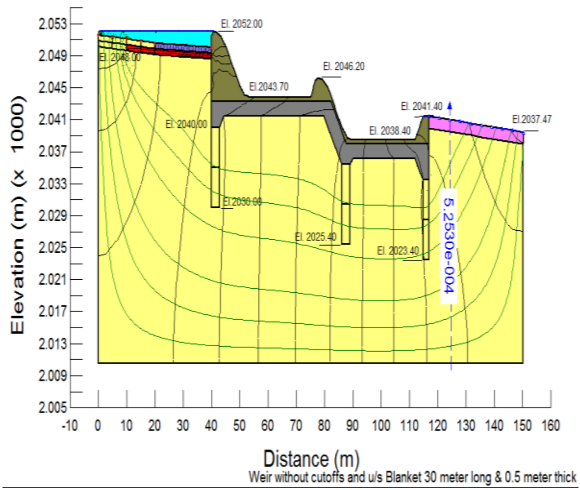

Fig. 7. Flow net for weir with up-stream blanket (30m long).

Figs. 8 and 9 give flow nets for the weir with upstream blanket of 20m and 30m in combination with the upstream, mid and downstream cut-offs. The flow nets generated for soil with flux sections, showing seepage quantities through foundation, present considerable reduction in seepage as compared to base case. The comparative statement of the seepage quantities and percent seepage reduction for the weir with different seepage control measures is shown in Table 1.

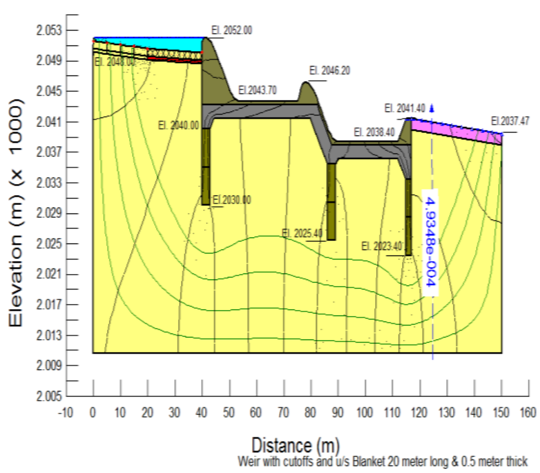

Fig. 8. Flow net for weir with 10m deep cut-off (U/S, D/S and Central) and blanket (20m long and 0.50m thick)

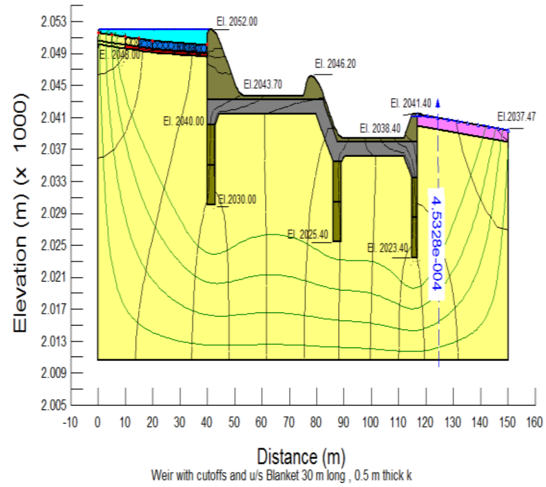

Fig. 9. Flow net for weir with 10 deep cut-off (U/S, D/S and Central) and blanket (30m long and 0.50m thick).

5.1 Exit Gradient Estimates and Cost Analysis

Table 1 shows that weir with downstream cut-off (10m deep) and upstream cut-off (10m deep) reduces the seepage by 14% as compared to the base case, while the weir with upstream blanket of 30m length (without cut-offs) reduce the seepage by 16%. As these seepage reductions are close to one another, therefore, for these two cases, further studies were carried out to estimate exit gradient as shown in Table 2 and costs comparison as shown in Tables 3 and 4.

The commonly adopted value of safe exit gradient for shingle material is equal to 1/4 to 1/5 (0.25 to 0.20), hence, the exit gradient is on safe side in the both cases; however, weir with upstream blanket of length 30m, thickness 0.5m (without cut-offs) is more on safe side as compared to weir with downstream cut-off (10m deep) and upstream cut-off (10m deep).

Table 1. Comparative statement of seepage reduction

S. No	Trial	Total seepage (m^3/sec/m)	% Seepage reduction
1	Weir without any measure as a base case.	6.2900e-4	
2	Weir with downstream filter	6.2900e-4	0
3	Weir with downstream cut-off (5m deep)	6.2899e-4	0
4	Weir with downstream cut-off (10m deep)	5.8652e-4	7
5	Weir with downstream cut-off (10m deep) and mid cut-off (5m deep)	5.7392e-4	9
6	Weir with downstream cut-off (10m deep) and mid cut-off (10m deep)	5.7369e-4	9
7	Weir with downstream cut-off (10m deep) and upstream cut-off (10m deep)	5.4084e-4	14
8	Weir with mid cut-off (10m deep), up stream cut-off (10m deep).	5.6330e-4	10
9	Weir with downstream cut-off (10m deep), mid cut-off (10m deep) and upstream cut-off (5m deep)	5.5588e-4	12
10	Weir with downstream cut-off (10m deep), mid cut-off (10m deep) and upstream cut-off (10m deep)	5.2845e-4	16
11	Weir with upstream blanket of length 20m and thickness 0.5m (without cut-offs).	5.7478e-4	9
12	Weir with upstream blanket of length 25m, thickness 0.5m (without cut-offs).	5.5272e-4	12
13	Weir with upstream blanket of length 30m, thickness 0.5m (without cut-offs)	5.2530e-4	16
14	Weir with upstream blanket of length 35m, thickness 0.5m (without cut-offs).	4.8367e-4	23
15	Weir with cut-offs and upstream blanket of length 20m and thickness 0.5m.	4.9348e-4	22
16	Weir with cut-offs and upstream blanket of length 25m, thickness 0.5m	4.7604e-4	24
17	Weir with cut-offs and upstream blanket of length 30m, thickness 0.5m	4.3653e-4	31
18	Weir with cut-offs and upstream blanket of length 35m, thickness 0.5m	4.3528e-4	31

Table 2. Exit Gradient Estimates

Sr. No.	Trials	Exit gradient value
1	Weir without any measure as a base case	$2.8274e^{-1} = 0.2827$
2	Weir with downstream cut-off (10m deep) and upstream cut-off (10m deep)	$7.0278e^{-2} = 0.0703$
3	Weir with upstream blanket of length 30m, thickness 0.5m (without cut-offs)	$5.9719e^{-2} = 0.0597$

Table 3. Cost for upstream and downstream cut-offs (each 10m deep)

Item Description		unit	Rate (Rs)	Quantity (m^3)	Cost (Rs)
Excavation	Down Stream Cut-off	m^3	941	1200	1,129,200
	Up Stream Cut-off	m^3	941	1800	1,693,800
Fill Concrete	Down Stream Cut-off	m^3	7191	1200	8,629,200
	Up Stream Cut-off	m^3	7191	1800	12,943,800
				Total Cost (Rs)	24,396,000

Table 4. Cost for upstream blanket of 30m length

Item Description	unit	Rate (Rs)	Quantity (m^3)	Cost (Rs)
Excavation for one meter length	m^3	941	150	141,150
Coarse San Bedding for one meter length	m^3	2203	30	66,090
GCL for one meter length	m^2	977	60	58,620
Coarse Sand Protection for one meter length	m^3	2203	30	66,090
Riprap Protection for one meter length	m^3	5614	60	336,840
			Total Cost (Rs) per meter length	668,790
			Total Cost (Rs) for 30 meter length	20,063,700

The above table shows that the cost of the weir with upstream blanket of length 30m, thickness 0.5m (without cut-offs) is less than the cost of the weir with downstream cut-off (10m deep) and upstream cut-off (10m deep).

6. Conclusions

The following conclusions are drawn from this study:

1. The weir foundation without provision of any seepage control measure offers a considerable amount of water to flow through foundation of the weir. So, an adequate system is needed to control the water losses through the foundation of the weir.
2. Providing cut-offs and an upstream impervious blanket is more effective in seepage control than the other seepage control measures. However, the efficiency of the blanket to reduce seepage was found as function of its length.
3. The seepage reduction effects of upstream blanket of length 30m, thickness 0.5m (without cut-offs) is approximately same as that of downstream and upstream cut-offs (each of 10m depth); however, the exit gradient for upstream blanket is more on safe side and also the cost of construction of blanket is less as compared to the cost of the cut-offs.
4. An upstream blanket of 30m length is recommended as the seepage control measure for the said weir.

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