Effect of Leakage Through Cutoff on Stability of Hydraulic Structures

by

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Introduction

The vertical cutoffs provided under impervious floor of hydraulic structures founded on permeable soils are primarily designed from scour/exit gradient considerations and are generally located at the end of impervious floor. They affect uplift pressure distribution below impervious floor, depending upon their position and depth. In case upstream cutoff is made deep enough to get properly embedded in the impervious strata underneath, the seepage is practically cutoff and uplift pressures may not be developed at all.

For design purposes the cutoffs are assumed to be perfectly impervious. But it may not be possible to ensure it due to site conditions, improper interlocking or corrosion etc. These may result in leakage through them. With such leaky cutoffs the uplift pressure distribution under the floor and exit gradient would get altered.

Ambraseys, Brahma (1972), Chawla (1975), and others have attempted analytical solution to the problem involving leaky cutoffs with different boundary conditions for two dimensional seepage. But practically in all hydraulic structures the seepage flow is rather three dimensional. Ramdurgaih (1963), has, however, studied the effect of leakage through central cutoff by three dimensional electrical analogy model. He has assumed the structure to be founded on permeable strata of finite depth. A more common case of structures with leaky and cutoffs founded on infinite previous strata has not been studied so far. The present paper deals with the effect of leakage, through upstream and downstream cutoff, on the uplift pressure and exit gradient below hydraulic structures.

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This paper was received in September 1978 and is open for discussion till the end of March, 1980.

Formulation of Problem

The pattern of pressure distribution under an impervious floor on permeable foundation depends upon its proflle. In all such structures the seepage under floor is three dimensional and pressure at any point under tne floor can be expressed as

$$3D = f(H, d, b, h_s, w) \qquad ...(1)$$

where H is head causing seepage, d is depth of cutoff, b is total floor length, h_s is hight of spring level and W is width of the structure.

This equation is based on the assumption that the cutoff are perfectly impervious. However, if there is some leakage through cutoff, the pressure distribution will get changed. It can now be expressed as

$$3D = f(H, d, b, h_s. w, k_1, k_2) \qquad ...(2)$$

where k_1 is the leaky area and k_2 is form factor depending upon location of such leakage.

Dimensional analysis gives the following equation,

$$3D = f\left(\frac{H}{d}, \frac{b}{d}, \frac{h_s}{H}, \frac{W}{b}, \frac{K_1}{d}, \frac{K_2}{d}\right) \qquad ...(3)$$

If all other parameters in equation 3 are kept constant and k_1/d and k_2/d are changed i.e. percentage or location of leakage is varied, the effect of such leakage on uplift pressure distribution can be observed. As such experimental studies have been carried out for different percentage and location of leakage in upstream, downstream cutoff and results have been given in the form of curves.

Mode of Representation of Leakage

No field data regarding the actual pattern and size of the openings in a sheet pile line, through which leakage is likely to take place, is available. However, it may be reasonable to assume that 5 percent to 6 percent of the total area of cutoff may become ineffective due to openings. Beyond this limit the efficacy of cutoff may get drastically reduced. Therefore, in the present study the percentage and pattern of leakage has been represented in the model to the extent mentioned above in a fashion detailed here in after. The open area has been taken as a percentage of the area of the cutoff and has been represented uniformly distributed over the cutoff (Figure 1). Three different cases of leakage through cutoff represented in the model are as below.

(*i*) Leakage through entire cutoff.

(*ii*) Leakage through upper half portion of cutoff.

(*iii*) Leakage through lower half portion of cutoff.

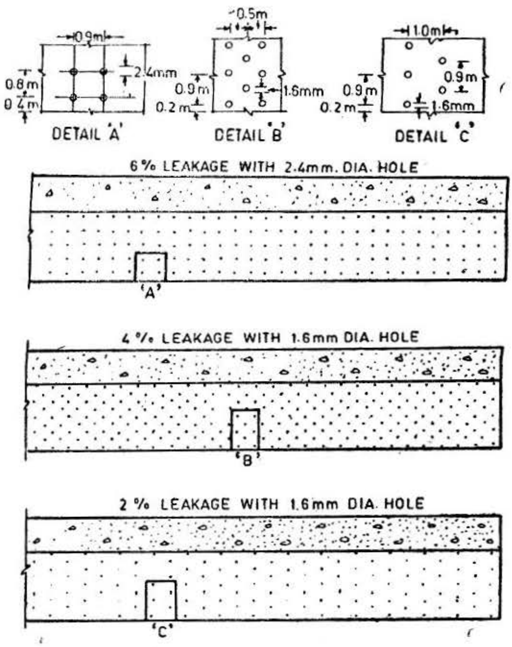

FIGURE 1 : Different percentage of leakage as represented in model

Experimental Details

Barrage being the most important and common hydraulic structure founded on permeable soil has been chosen for the study. The head regulator portion has not been represented.

The experimental set-up consisted of an electrolytic tray built of seasoned teak wood made insulating and leakproof from all sides and bottom by means of soft wax and other leak-proof compounds. A barrage model showing the foundation profile accurately was made of well seasoned teak wood to a scale of 1/100. The model was baked in the molten wax and thereafter fitted in the electrolytic tray in inverted position. The upstream and downstream river bed surfaces were simulated by copper plates. The length of these plates was kept equal to half the floor length. The upstream copper plate was given 100 per cent potential representing head causing seepage and the downstream plate was given 0 per cent potential representing the drained bed. Simple tap water, used as electrolyte, was filled in the tray to represent the pervious subsoil. The depth of electrolyte was kept more than half the floor length to represent infinite depth of pervious strata. In the experimental study the depth of electrolyte has been kept more than $5D$ where D is depth of cutoff (Kulandaiswamy and Muthu-Kumaran, 1972 *c*). Figure 2 shows the general layout plan of the barrage.

The uplift pressures and the exit gradients have been determined with upstream river being at pond level and the downstream drained at bed level.

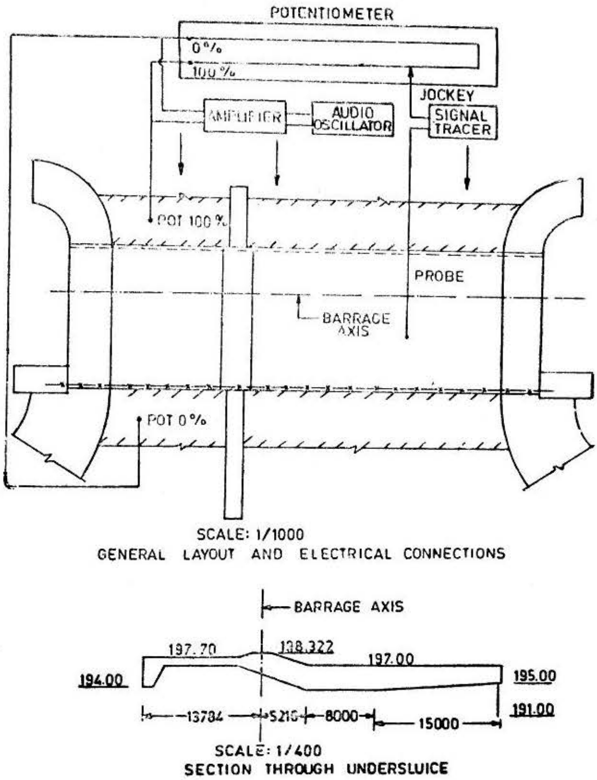

FIGURE 2 Plan with electrical connections

Observations

Three dimensional electrical analogy experiments have been conducted for the following cases—

A—Leakage Through Downstream Cutoff

(*i*) 2, 4 and 6 percent leakage uniformly distributed over entire cutoff.

(*ii*) 2, 4 and 6 percent leakage distributed over upper half portion only.

(*iii*) 2, 4 and 6 percent leakage distributed over lower half portion only.

(*iv*) Without any leakage.

B—Leakage Through Upstream Cutoff

(*i*) 6 percent leakage only in upper half portion.

(*ii*) 100 percent leakage *i.e.* without any cutoff.

(*iii*) Without any leakage.

The uplift pressures along the end section and central section of the barrage have been observed with different area and pattern of openings.

The exit gradient has also been worked out along these sections for various test conditions.

Results

The observed uplift pressure 'ϕ', percentage of total head, has been plotted against the parameter x/b, where 'x' is the distance of point under consideration from upstream end and 'b' is the total floor length, for different pattern of leakage for right end and central section of the barrage. Figures 3 and 4 show the curves with 2, 4 and 6 percent leakage in downstream cutoff distributed over its entire depth, for end section and central section respectively. These plots indicate the effect of different percentage of leakage with same pattern and location of openings. Figures 5 and 6 give the plots for 2 percent leakage in upper half, lower half and entire depth of downstream cutoff for end and central section respectively. These plots indicate the effect of location of leakage on the uplift pressures. Similarly Figures 7, 8, 9 and 10 show the curves for 4 and 6 percent leakage. Figures 11 and 12 show the curve for 6 percent leakage in the upper half of the upstream cutoff along with curves for with and without upstream cutoff for end and central section respectively. The values of exit gradient for these conditions are given in Table 1 for end and central sections of the structure.

Analysis

(*a*) *Uplift Pressures with Leakage Through the Downstream Cutoff*

Perusal of results plotted in Figures 3 and 4 indicate that due to leakage through downstream cutoff uplift pressures below the floor get reduced. The effect is pronounced near the cutoff and goes on reducing

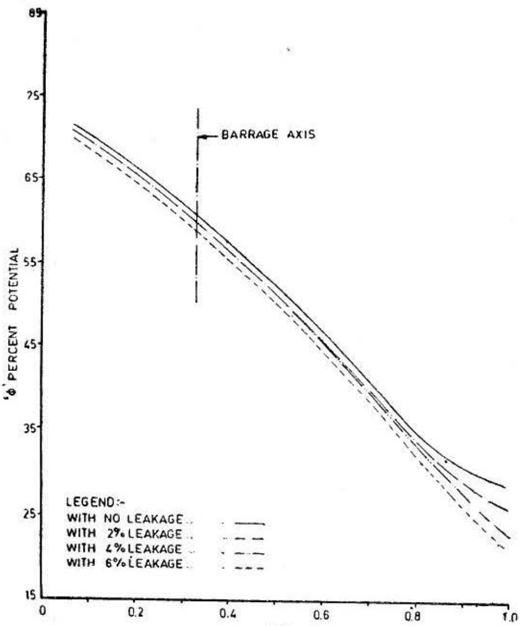

FIGURE 3 **Potentials with leakage through entire D/S cutoff along right end section**

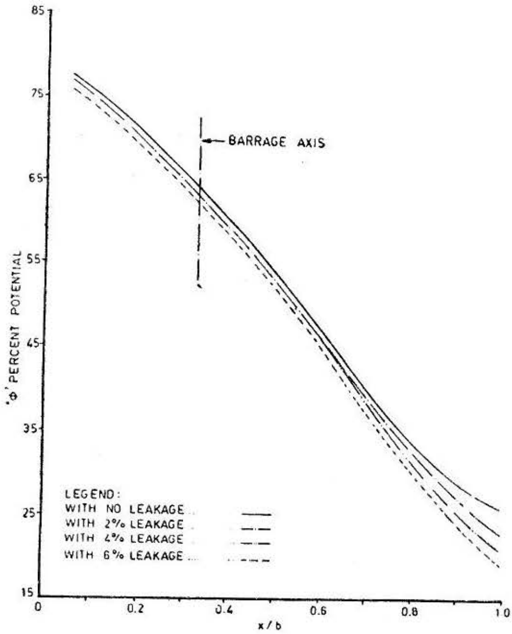

FIGURE 4 Potentials with leakage through entire D/S cutoff along central section

towards upstream. With 2 percent leakage distributed uniformly over the entire cutoff, the reduction in uplift pressure at the downstream end of the floor is of the order of 3 percent, whereas with 4 and 6 per cent, the reduction is about 6 and 8 percent respectively. The reduction in pressures along end section and central section is almost the same.

TABLE 1

Values of exit gradient

Conditions	Value of exit gradient		
	Right end section	Central section	Left end section
Without leakage through cutoff	1/5.26	1/7.30	1/5.43
2 per cent leakage through down-stream cutoff.			
(*i*) In entire depth	1/4.38	1/6.73	1/4.88
(*ii*) In lower half portion	1/4 78	1/6.85	1/5.18
(*iii*) In upper half portion	1/4.32	1/6.49	1/4.88
4 per cent leakage through downstream cutoff.			
(*i*) In entire depth	1/4.15	1/6.22	1/4.60
(*ii*) In lower half portion	1/4.63	1/6.57	1/5.05
(*iii*) In upper half portion	1/4.15	1/5.71	1/4.18
6 per cent leakage through downstream cutoff			
(*i*) In entire depth	1/3.94	1/6.13	1/4.23
(*ii*) In lower half portion	1/4.50	1/6.62	1/4.76
(*iii*) In upper half portion	1/3.62	1/5.52	1/3.98

The location of openings in the cutoff is quite significant. It influences the uplift pressures appreciably. Figures 5 to 10 show the uplift pressures observed with three different locations of openings. Maximum reduction

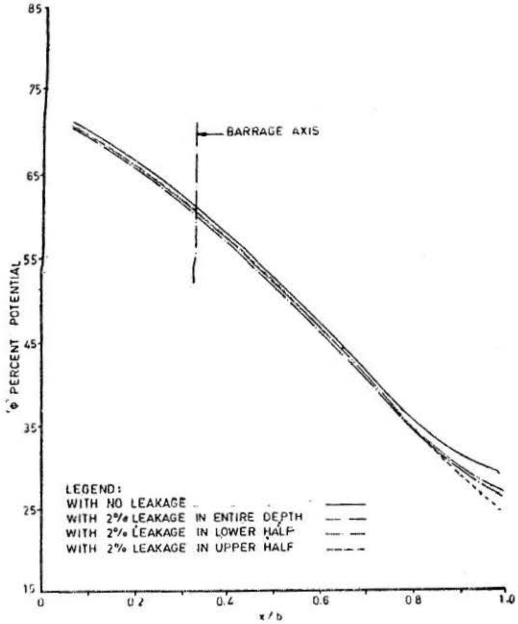

FIGURE 5 Potentials with 2 percent leakage in different parts of D/S cutof along right end section.

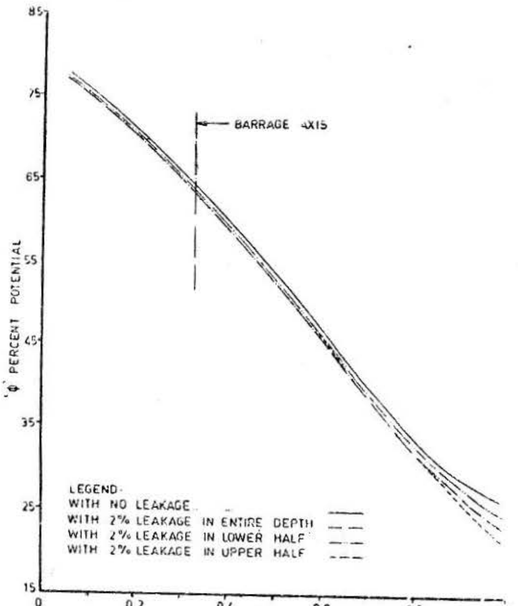

FIGURE 6 Potentials with 2 percent leakage in different parts of D/S cutoff along central section.

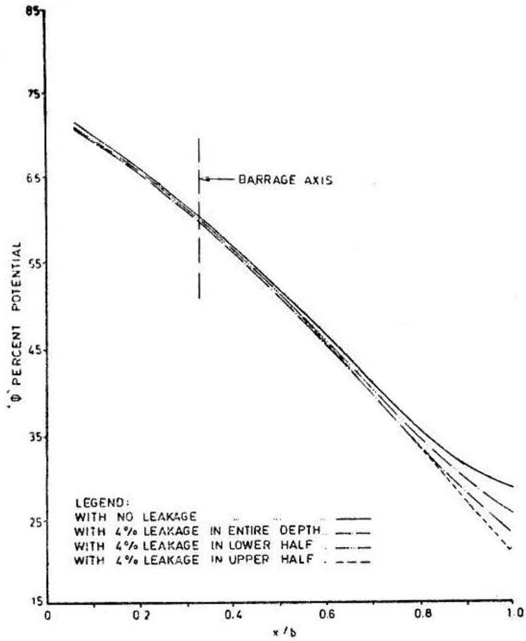

FIGURE 7 Potentials with 4 percent leakage in different parts of D/S cutoff along right end section.

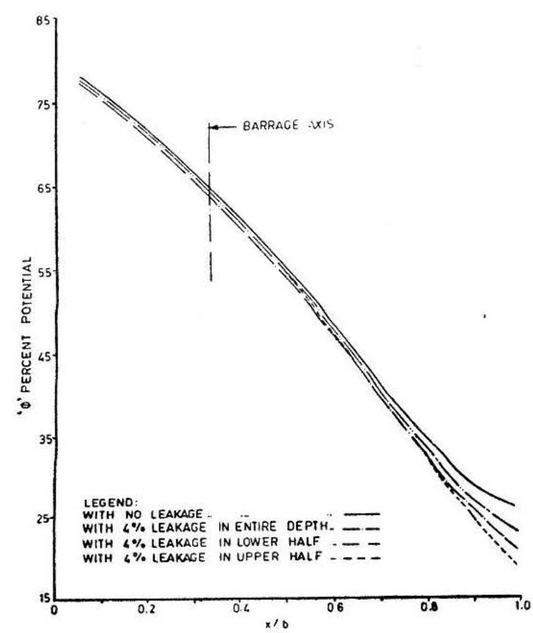

FIGURE 8 Potentials with 4 percent leakage in different parts of D/S cutoff along central section.

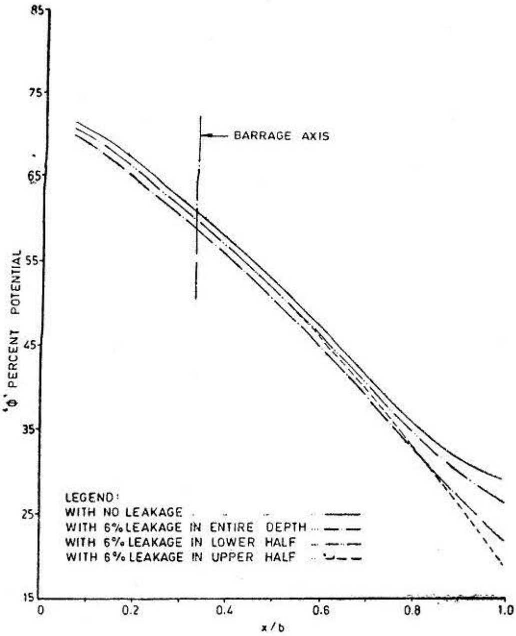

FIGURE 9 Potentials with 6 percent leakage in different parts of D/S cutoff along right end section.

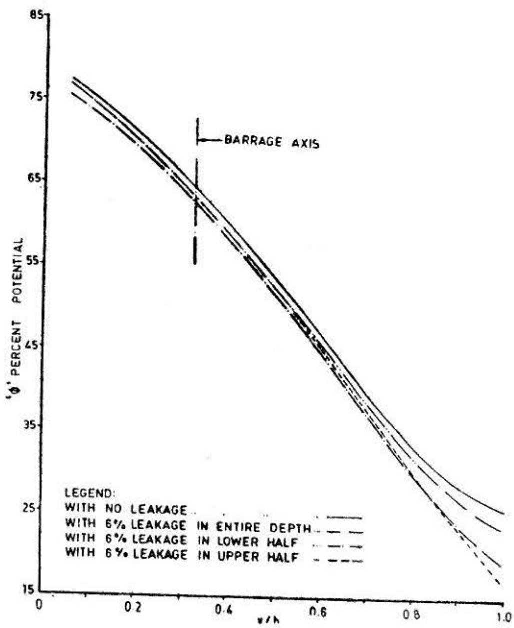

FIGURE 10 Potentials with 6 percent leakage in different parts of D/S cutoff along central section.

occurs when the leakage is in the upper half portion and the minimum when leakage is in the lower half portion. The curve for the condition when leakage is through entire depth lies in between the two. With 6 per cent leakage in the upper half portion uplift pressures are reduced by 11 percent near the downstream end of the floor along end section. The corresponding decrease for the condition when leakage takes place through entire cutoff and lower half portion is 8 and 3 percent respectively (Figure 5). At central section the effect of leakage is of the same order.

The plotting shown in Figures 5 to 10 indicate that the leakage in the upper half portion is most effective and causes maximum reduction in uplift pressures near the cutoff. But its effect diminishes rapidly towards upstream so much so that the pressures observed with leakage in entire cutoff become lowest, reason being that the effect of leakage through upper half is more localized. It does not intercept the deeper flow lines where as in other case, the deeper flow lines are also intercepted.

(b) Uplift Pressures with Leakage Through Upstream Cutoff

Leakage through the upstream cutoff increases the uplift pressures below the floor as indicated in the Figures 11 and 12. 6 percent leakage in the upper half portion of the cutoff causes 5 percent increase in the uplift pressure. The effect of leakage does not travel long and becomes almost negligible beyond one fourth length of the floor. The complete removal of cutoff does not increase the pressures more than 9 percent and its effect hardly goes upto the middle of the floor. However, in case where length of upstream floor is small as compared to total floor length, the effect of leakage may extend even under downstream floor.

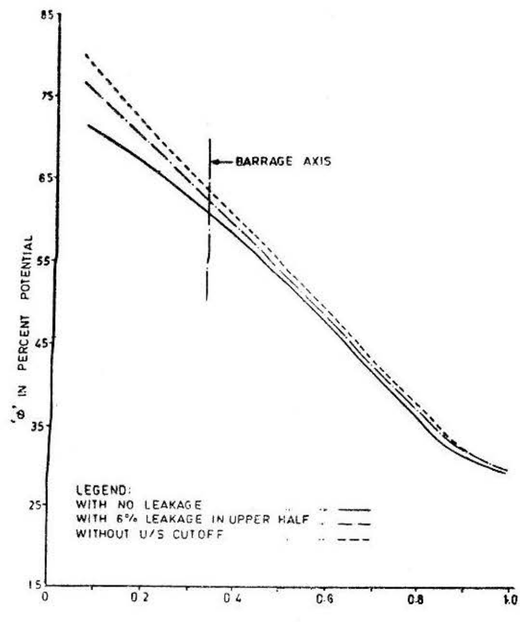

FIGURE 11 Potentials with 6 percent leakage through U/S cutoff along right end section.

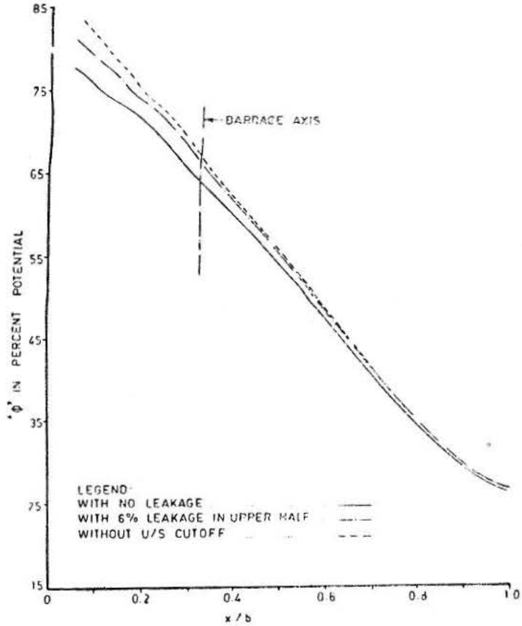

FIGURE 12 Potentials with 6 percent leakage through U/S cutoff along central section.

Exit Gradient

A persual of results gives in Table 1 indicates that the leakage affects the exit gradient significantly. Even 2 percent leakage in the upper half portion increases the value of exit gradient from 1/5.26 to 1/4.3, thereby reducing the factor of safety against piping by about 22 percent. With 6 percent leakage in the upper half portion, reduction in factor of safety works out to 45 percent. The effect of leakage through other two locations of the cutoff is comparatively lesser. Leakage through upstream cutoff does not affect the exit gradient at all.

The ratio of the floor length to the depth of cutoff (b/d) influences the uplift pressures and exit gradient, however, its effect for values greater than 5 has not been found to be significant (Chawla, 1975). In most of the practical cases of the value of b/d ratio is more than five. In the present study also, its value has, therefore, been taken as 7.

Conclusions

1. Leakage in downstream cutoff decreases uplift pressures under the floor, the effect being more in the vicinity of the cutoff.

2. Leakage through the upper portion of downstream cutoff is most effective.

3. Leakage through upstream cutoff increases the pressures under the floor. With six per cent leakage the increase in pressures extends upto 1/4th of the floor length.

4. The exit gradient is effected appreciably by leakage through the downstream cutoff.

5. With 6 percent of leakage in downstream cutoff the factor of safety against piping may be reduced to half of a fully effective pile.

6. Leakage through upstream cutoff has not affected the value of exit gradient.

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