

# Permeability of Sloping Soil Layer: An Experimental Study



M. Kafi, J. Alam, M. Muzzammil, and M. U. Haque

**Abstract** Permeability is an important property influencing flow-through porous media. Seepage of water through earth dams, stability of slopes and ground water recharge are some of the problems related to permeability of soil. The accurate determination of permeability is a cause of concern to the hydraulic engineers. As the stratification of earth crust exists in any direction, the study of permeability of soil is imminent in multiple directions. Although ample work has been reported regarding the permeability of soil in horizontal and vertical directions, the work on inclined layer seems to be sparse in the literature. Therefore, permeability of sloping soil layer has been investigated in this paper. Four samples of fine sand were selected from different sites for the experimentation. Permeability has been determined for horizontal layer, for positively as well as negatively sloped layer. Inclination of layer was varied from  $0^\circ$  to  $\pm 20^\circ$ . With the increase in inclination with respect to horizontal, the permeability of positively sloped layer was found to increase, whereas for the negatively sloped layer, it was found to decrease. When the slope was increased from  $0^\circ$  to  $+20^\circ$ , the maximum deviation of  $-27\%$  was observed between the observed permeabilities of horizontal and positively sloped layer, whereas for the opposite slope, i.e., from  $0^\circ$  to  $-20^\circ$ , the maximum deviation found was  $34\%$ . For a constant slope, the permeability of the said layers was found to increase with the particle size.

**Keywords** Observed permeability · Horizontal layer · Sloping layer · Porous media

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## 1 Introduction

Permeability is an intrinsic soil property. This property plays a major role in seepage of water through the earth dams, foundations, soil erosion, soil pollution, settlement of buildings, stability of roads and even yield of crop. Its importance has further been increased due to its pivotal role in presenting a solution to the problems of environmental control, dewatering and filtration process. The drainage through soil and thus the permeability assume a matter of high significance to hydraulic engineers, hydrologist and geologists.

The flow of water in earth crust takes place in vertical and horizontal directions and at any inclination. Determination of permeability thus becomes imminent in all the directions. A number of investigators have worked for the determination of permeability in vertical directions as Kenney [1], Shepherd [2], Okagbue [3], Sridharan and Prakash [4], Gupta et al. [5], Koomishi and Azarhoosh [6]. Alam et al. [7] carried out experiments to find out the horizontal permeability of some materials along with CFD simulation. Alam et al. [8] carried out the experimental work on stratified soils to determine the permeability in horizontal as well as in vertical directions with CFD simulation. Many investigators have determined the permeability both in vertical and horizontal directions, notable among them are Aronvici and Donman [9], Evans [10], Chan and Kenney [11], Dungca and Galpino [12], Shedid [13]. But, the work on permeability for sloping soil layers seems scarce in the literature. Thus, the present study was undertaken to investigate the pattern of permeability of sloping layers. Experiments have been conducted on the positively sloped layers as well as negatively sloped layers.

## 2 Methodology and Experimental Setup

The material selected for the study was fine sand as this material is frequently found in the water bearing strata. Thus, the study of movement of water through fine sand will be more useful as compared to other soil types. The material was collected from four different sites. Sieve analysis of the selected material was carried out as per IS: 2720 Part-IV 1985. The gradation curve for the said materials was plotted to ascertain the particle size range, as shown in Fig. 1.

The samples have been named as FS-1, FS-2, FS-3 and FS-4 on the basis of range of particle size. FS-1 is being the sample having finest particle size and FS-4 was having the coarser particles as evident from the figure. For the determination of permeability for the sloping layer, as no standard equipment was available, the horizontal permeameter fabricated at the Department of Civil Engineering, Aligarh Muslim University, was used for the purpose with slight modification. A layer of clay was laid at a slope of  $10^\circ$  and  $20^\circ$  to the horizontal, respectively, and the sample of fine sand layer with 15 cm thickness was placed over clay layer. Thereafter, another clay layer was placed above the sample. So, the fine sand layer was sandwiched

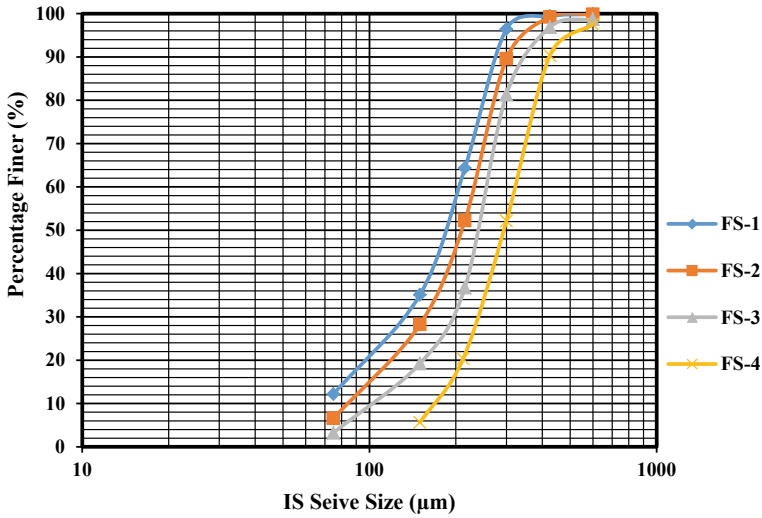
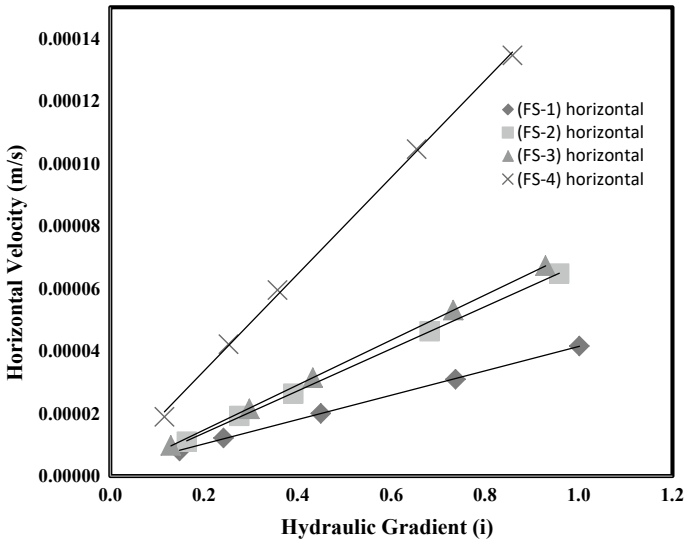


Fig. 1 Grain-size distribution curves for four samples of fine sand

between the clay layers. Water was allowed to flow through the sand layer to make it completely saturated. Sufficient time was allowed to stabilize the water level in inlet as well as outlet tube to get the accurate head loss occurring through the sample. For the accurate measurement of discharge, the measurement of time interval and the volume of water collected were done with utmost care. The arrangement is shown in Fig. 2.



Fig. 2 Permeability determination for inclined fine sand layer



**Fig. 3** Variation of horizontal velocity with hydraulic gradient for materials at  $0^\circ$  slope

The permeability of sand layer was initially determined keeping the layers in horizontal direction or  $0^\circ$  slope. For the determination of permeability, the variation of velocity was plotted against the hydraulic gradient of the sample at  $0^\circ$  slope. This variation is shown in Fig. 3. The slope of the curve gives the average permeability of the sample. Similarly, the variation of velocity with hydraulic gradient for  $+10^\circ$  slope and  $-10^\circ$  slope is shown in Figs. 4 and 5, respectively, and for the slope of  $+20^\circ$  and  $-20^\circ$  is shown in Figs. 6 and 7, respectively.

Initially, the layer of fine sand was placed at a slope of  $+10^\circ$  and then  $-10^\circ$  with respect to horizontal. Thereafter, the slope of the layers was increased to  $+20^\circ$  and  $-20^\circ$ . The observations were recorded and permeability was determined for the above four cases for all the samples with the help of above figures.

### 3 Results and Discussion

The analysis of the experimental data of permeability of sloping layers on designated inclination and the obtained inferences are presented below.

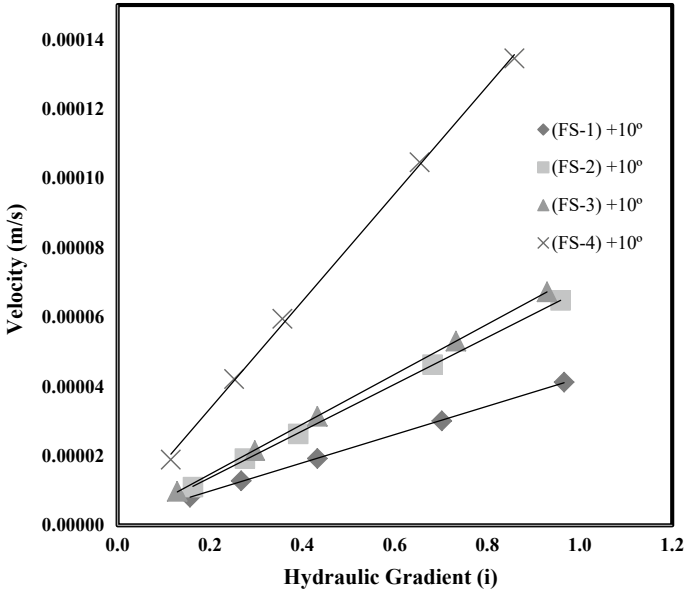


Fig. 4 Variation of velocity with hydraulic gradient for 10° negative slope

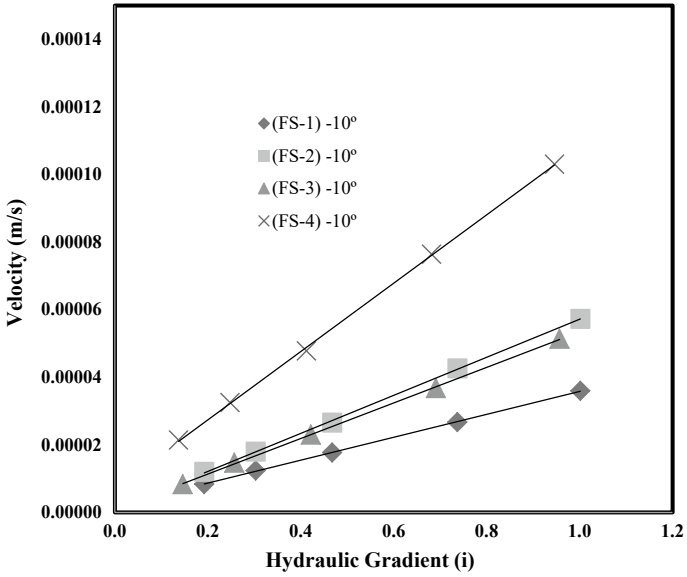


Fig. 5 Variation of velocity with hydraulic gradient for 10° positive slope

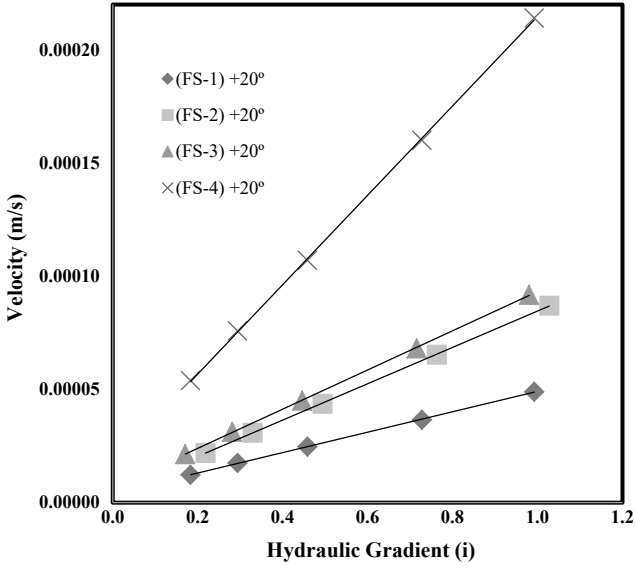


Fig. 6 Variation of velocity with hydraulic gradient for 20° positive slope

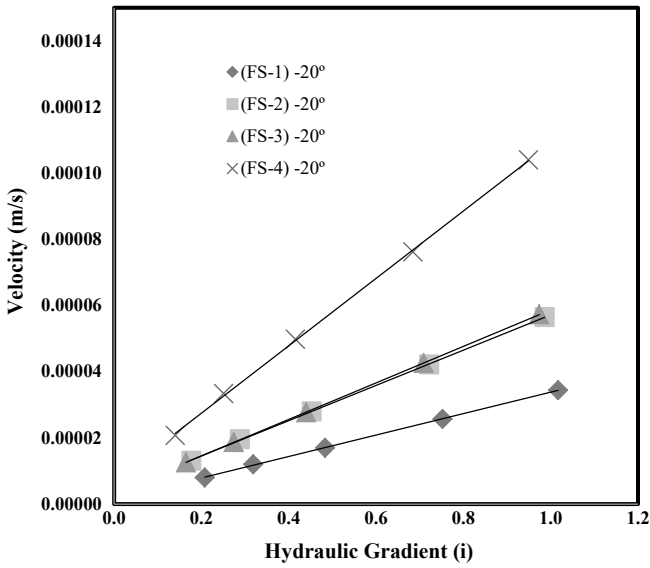


Fig. 7 Variation of velocity with hydraulic gradient for 20° negative slope

**Table 1** Permeability of fine sand inclined at 0° and at 10°

S. No.	Soil combinations	Observed permeability (m/s)		Percent deviation
		0° slope	10° positive slope	
1	Fine sand-1 (FS-1)	3.90E-05	4.07E-05	- 4.36
2	Fine sand-2 (FS-2)	6.74E-05	7.73E-05	- 14.7
3	Fine sand-3 (FS-3)	7.20E-05	8.37E-05	- 16.3
4	Fine sand-4 (FS-4)	1.55E-04	1.89E-04	- 21.9

**Table 2** Permeability of fine sand inclined at 0° and at - 10°

S. No.	Soil combinations	Observed permeability (m/s)		Percent deviation
		0° slope	10° negative slope	
1	Fine sand-1 (FS-1)	3.90E-05	3.39E-05	13.1
2	Fine sand-2 (FS-2)	6.74E-05	5.63E-05	16.5
3	Fine sand-3 (FS-3)	7.20E-05	5.26E-05	26.9
4	Fine sand-4 (FS-4)	1.55E-04	1.01E-04	34.8

### 3.1 Permeability at 10° Slope

The permeability of fine sand layer in horizontal direction and at +10° slope is presented in Table 1. It can be seen from Table 1 that permeability of positively sloped layer has increased with respect to the permeability in horizontal direction. Moreover, the permeability of the samples can be seen on a rising trend with increase in particle size. The deviation between horizontal permeability and positively sloped layer is thus found to have negative values.

Thereafter, the slope was reversed, i.e., fine sand layer was placed at -10° slope. The values of permeability obtained for this case are presented in Table 2 along with the values of permeability of same material in horizontal direction.

The permeability of negatively sloped layer was found to decrease as compared with the horizontal permeability. The percentage deviation was thus positive. However, with the increase in particle size, a rise in permeability was noticed for negative slope case. The maximum deviation observed in case of negative slope of 10° was obtained as 34.8%, whereas for the case of positive slope, the maximum deviation was found as -21.9%.

### 3.2 Permeability at 20° Slope

The slope of the fine sand layer was increased to 20°. In this case also, the permeability of positively sloped layer was found to increase when compared with corresponding horizontal permeability values. Thus, the percent deviation was negative as shown in

**Table 3** Permeability of fine sand inclined at 0° and at 20°

S. No.	Soil combinations	Observed permeability (m/s)		Percent deviation
		0° slope	20° positive slope	
1	Fine sand-1 (FS-1)	3.90E-05	4.52E-05	- 15.9
2	Fine sand-2 (FS-2)	6.74E-05	8.03E-05	- 19.1
3	Fine sand-3 (FS-3)	7.20E-05	8.65E-05	- 20.1
4	Fine sand-4 (FS-4)	1.55E-04	1.97E-04	- 27.1

**Table 4** Permeability of fine sand inclined at 0° and at - 20°

S. No.	Soil combinations	Observed permeability (m/s)		Percent deviation
		0° slope	20° negative slope	
1	Fine sand-1 (FS-1)	3.90E-05	3.24E-05	16.9
2	Fine sand-2 (FS-2)	6.74E-05	5.32E-05	21.1
3	Fine sand-3 (FS-3)	7.20E-05	5.51E-05	23.5
4	Fine sand-4 (FS-4)	1.55E-04	1.02E-04	34.2

Table 3. But, the deviation in values of permeability horizontal layers and the permeability of sloping layer at 20° slope was found to be higher than the corresponding values of deviation at 10°. In the former case, the maximum deviation was -21.9%, while for latter case, it was -27.1% (Tables 1 and 3).

After the experiment on positive slope of fine sand layer, the slope was changed to -20°. The values of permeability obtained for negative slope case is presented in Table 4 along with the values of permeability of same material in horizontal direction.

In general, the values of permeability for negatively sloped layer were found to be lesser than the corresponding values of horizontal permeability of the same layers. For -20° slope, the deviation between horizontal permeability and the permeability of sloped layer was found to be higher than the corresponding layers at -10° slope but only for the finer particle fragment. For coarser particle fragment, the corresponding deviation for -20° slope was slightly lesser as compared to -10° slope (Tables 2 and 4).

Comparison of deviation of permeability of layers inclined at +10° and - 10° with the deviation of permeability of layers in horizontal direction is shown in Table 5 and for the layers at slope of +20° with - 20° with horizontal layers is shown in Table 6.

With increase in slope from 10° to 20°, an increase in values of percent deviation was noticed for positively sloped layers. But for negatively sloped layers, the increase in percent deviation was noticed only for finer fraction of sand, while for coarser fraction, a slight decrease was observed. The minimum percent deviation was obtained for the finest sand (FS-1), and an increase in percent deviation was observed with the increase in particle size. Maximum percent deviation was obtained for the coarser sand (FS-4). When the permeability of +10° sloped layer and -10° sloped layer was



**Table 5** Deviation of permeability of fine sand inclined at  $10^\circ$  and  $-10^\circ$  with horizontal

S. No.	Soil combinations	Deviation of permeability (%)	
		$10^\circ$ positive slope	$10^\circ$ negative slope
1	Fine sand-1 (FS-1)	- 4.36	13.1
2	Fine sand-2 (FS-2)	- 14.7	16.5
3	Fine sand-3 (FS-3)	- 16.3	26.9
4	Fine sand-4 (FS-4)	- 21.9	34.8

**Table 6** Deviation of permeability of fine sand inclined at  $20^\circ$  and  $-20^\circ$  with horizontal

S. No.	Soil combinations	Deviation of permeability (%)	
		$20^\circ$ positive slope	$20^\circ$ negative slope
1	Fine sand-1 (FS-1)	- 15.9	16.9
2	Fine sand-2 (FS-2)	- 19.1	21.1
3	Fine sand-3 (FS-3)	- 20.1	23.5
4	Fine sand-4 (FS-4)	- 27.1	34.2

compared with respective permeability of horizontal layer (Table 5), it was found that the magnitude of the deviation of negatively sloped layer was more as compared to the deviation of positively sloped layer. Similar trend can be observed in Table 6, where the deviation of positive  $20^\circ$  sloped layer is lesser than the deviation of negative  $20^\circ$  sloped layer. It indicates that for positively sloped layer, the percentage increase in permeability is less than the percentage decrease in permeability for negatively sloped layer when compared with respective horizontal permeabilities. If the slope is kept constant, the difference between deviation of permeability of positive and negative sloping layers increases with increase in particle size.

## 4 Conclusion

From the present study, the following conclusions may be drawn:

- Permeability of positively sloped layer was found to increase, whereas for negatively sloped layer the permeability was found to decrease with respect to horizontal permeability of same layers.

- For positively sloped layer, at the same slope, the percentage increase in permeability is less than the percentage decrease in permeability for negatively sloped layer when compared with respective horizontal permeabilities.
- At constant slope, the deviation of permeability between positively and negatively sloped layers was found to increase with increase in particle size.

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