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Research paper

Determination of Hydraulic Conductivity for Pure Gravel, Pure Sand And Grain Mixtures

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Abstract

The colmation process which describes the infiltration of fine sediments into the river beds is prominent for many years. However, due to the lack of knowledge and the absence of specific parameters, the colmation cannot be properly described. Therefore, hydraulic conductivity can be a virtuous way to describe this process. The aim of this study is to determine the hydraulic conductivity of gravel and sand mixtures. By using the KSAT device, hydraulic conductivity values from the laboratory samples were determined. Based on the data obtained from the experiment, the threshold of grain size distribution and hydraulic conductivity for the laboratory samples were established. The results show that when there is high percentage of coarse particle in a mixture compared to the percentage of the fine particle, the value of hydraulic conductivity tends to increase.

Keywords: *Colmation; Grain size distribution; Gravel; Hydraulic conductivity; Sand.*

1. Introduction

Morphological and sedimentological quality of a river bed and the connection of river ecology are coming more into focus nowadays. As for the problem of colmation, which describes the infiltration of fine sediments into the river beds, is well known for many years. Colmation process occurs during the interaction between the groundwater and surface water. This process arises when fine particles which transported by groundwater are obstructed in gaps of skeleton. These particles produce less porosity and permeability of porous medium while the density of the material sedimentation increases [1]. The colmation is also known as the inverse process of suffusion which is the process of permeating or infusing something with a substance, in the basic understanding of mechanical process. Besides that, according to [2], the stream bed's colmation can cause a reduction of pore volume, a consolidation of the filter medium and a minimization of the permeability of stream beds.
Colmation layers can form by a number of mechanisms associated with suspended sediment transport along river channels [3-5]. During the waning stages of floods or in still water areas of river channels, fine- grained sediment settles out of suspension, covering gravel bars and the channel bed. As these sediments settle, they fill the spaces of gravel bars, clogging the spaces between larger gravel clasts. These fine sediments may eventually move through the profile of the gravel bar, resulting in the formation of a colmation layer within the bar itself. Alternatively, additional sheets of gravel may be deposited atop the gravel bar, burying the mud drape and the previous gravel surface.
Colmation harms vertical connectivity and could have severe effects on river ecosystem function [6]. In the absence of scouring spates, the main direct physical effect is a reduction in habitat availability [7]. Besides that, colmation also changed the biogeochemical conditions of habitats for example shifting from oxic to anoxic conditions and increasing toxicant concentrations [8]. Furthermore, colmation process may affect the pollutant transportation between the groundwater and the surface water. It can reduce the amount of pollutant from penetrate into the groundwater which cause the pollutant to deposited at the river bed. This pollutant may cause bad impact to the river ecosystem but also can give positive and negative influence for the algae and other microorganism growth.
Subsurface colmation can be assessed by using indirect method, such as the measurement of hydraulic conductivity [9-10]. The hydraulic conductivity of a streambed is a measure of the substrate ability to transmit water through pore spaces. As been widely known, saturated hydraulic conductivity is one of the most important parameters for soil-water-plant interactions, water and solute movement and retention through the soil profile. It is a critically important parameter for estimation of various other soil hydrological parameters necessary for modelling flow through the naturally unsaturated vadose zone. According to [11-13], among different soil hydrological properties, hydraulic conductivity is reported to have the greatest statistical variability.
The hydraulic conductivity can be measured on soil samples in the laboratory and sometimes tests carried out in the field. The flow of water through the porous media is described by Darcy's law. Darcy's law assumes that the flow rate through a media is directly proportional to the applied hydraulic gradient, and therefore the flow rate versus the hydraulic gradient relationship is linear [14]. The hydraulic conductivity can be estimated in small-scale field experiment for example by slug tests. Nevertheless, simple test as the falling head slug test consists in measuring the infiltration time of a known volume of water into the subsurface zone and estimates the local horizontal hydraulic conductivity of the sediments. This method can be used as a surrogate for colmation measurement, because an increase in the proportion of subsurface fine

sediments results in the reduction of hydraulic conductivity [2, 15].

2. Methodology

2.1. Method

Data of hydraulic conductivity have been obtained by using KSAT device which placed in the laboratory in the Institute for Modelling Hydraulic and Environmental Systems. The KSAT device is used for measuring the hydraulic conductivity of saturated soil samples in a UMS sample ring. The method is based on German standards DIN 19683-9 and DIN 18130-1 and uses the Darcy's equation. Besides that, for this experiment falling head technique was used. The data collected is then tabulated and analysed in order to get good results for the research. Microsoft excel being used to analyse the data obtain from KSAT device.

2.1. Samples

The laboratory samples were divided into pure gravel, pure sand and also several mixtures of gravel and sand. The samples were taken which it is available in the laboratory itself. For this study, several sizes of sediments have been chosen and there are 31 samples in total for laboratory sample. For pure gravel, a grain size of 2.5 to 5.6 mm (E), 6.3 mm (G) and 10 mm (F) have been chosen. While for pure sand, a grain size of 0.25 to 0.5 mm (A), 2.0 to 3.5 mm (B), 1.0 to 2.5 mm (C) and 0.1 to 0.5 mm (D) were chosen. There are several mixtures of gravel and sand for this study by using previous pure gravel and pure sand that have been chosen. They are divided into two which have two ratios and three ratios of mixtures. The mixtures were decided depend on the performance of pure gravel and pure sand hydraulic conductivity.

3. Results and Discussion

3.1. Hydraulic Conductivity for Pure Gravel and Pure Sand

From the information obtained, Fig. 1 depicts a box plot diagram that represents the hydraulic conductivity of pure gravel and pure sand for grain size 0.25 to 0.5 mm (A), 1.0 to 2.5 mm (C), 0.1 to 0.5 mm (D) and 2.5 to 5.6 mm (E). While for grain size 2.0 to 3.5 mm (B), 6.3 mm (G) and 10 mm (F) the value of hydraulic conductivity cannot be defined. From the diagram, it can be seen that for A, C and D variants of hydraulic conductivity is small. Notwithstanding, for E the variation of the value is larger. Table 1 summarizes the minimum, median and maximum value of hydraulic conductivity for grain size A, C, D and E.

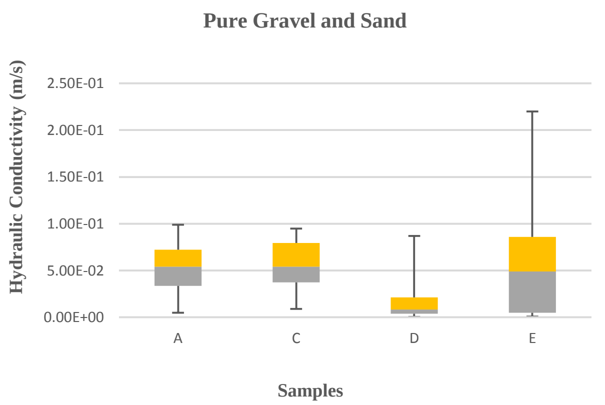

Fig. 1: Box plot diagram represents hydraulic conductivity of pure gravel and pure sand

Table 1: Summary of hydraulic conductivity for pure gravel and pure sand

Sample	A	C	D	E
Minimum	5.00×10^{-3}	9.00×10^{-3}	5.00×10^{-4}	1.00×10^{-3}
Median	5.40×10^{-2}	5.40×10^{-2}	8.50×10^{-3}	4.90×10^{-2}
Maximum	9.90×10^{-2}	9.50×10^{-2}	8.70×10^{-2}	2.20×10^{-1}

3.2. Hydraulic Conductivity for Pure Gravel and Sand Mixtures (2 Ratios and 3 Ratios)

Fig. 2 shows a box plot diagram that signifies the hydraulic conductivity for different percentages of ratios for gravel and sand mixture. For mixture 1, 6, 8 and 10 the variation of hydraulic conductivity value is smaller compared to the variance of mixture 5, 7, 11, 12, 13 and 15. Nevertheless, for mixture 2, 3, 4, 9, 14 and 16 the measurement of hydraulic conductivity cannot be defined. By comparing the value hydraulic conductivity between mixture 1 and 13, the variation of the value is larger because of mixture 13 consist high percentage of coarse particle which is 30% grain size 0.1 to 0.5 mm and 70% grain size 2.5 to 5.6 mm. In contrast, mixture 1 comprises a small amount of coarse particle which is 50% grain size 1.0 to 2.5 mm and 50% grain size 0.1 to 0.5 mm. Table 2 shows a summary of hydraulic conductivity value for the mixture that comprises of two ratios of pure gravel and sand.

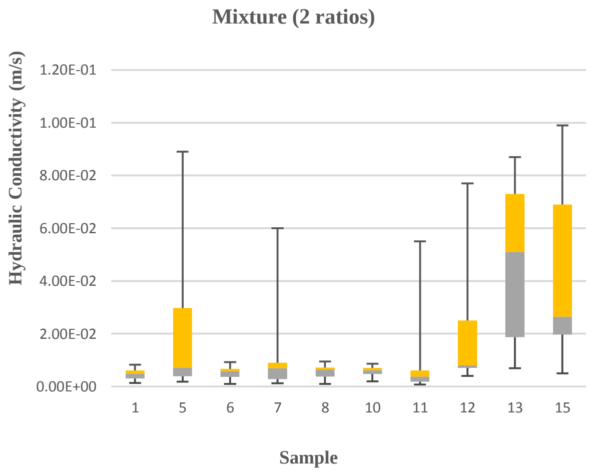

Fig. 2: Box plot diagram represents hydraulic conductivity of pure gravel and pure sand

Table 2: Summary of hydraulic conductivity for pure gravel and sand mixture (2 ratios)

Sample	1	5	6	7
Minimum	1.30×10^{-3}	1.90×10^{-3}	1.00×10^{-3}	1.20×10^{-3}
Median	4.85×10^{-3}	7.05×10^{-3}	5.85×10^{-3}	6.90×10^{-3}
Maximum	8.30×10^{-3}	8.90×10^{-2}	9.20×10^{-3}	6.00×10^{-2}
Sample	8	10	11	12
Minimum	1.00×10^{-3}	2.00×10^{-3}	7.00×10^{-4}	4.00×10^{-3}
Median	6.40×10^{-3}	6.20×10^{-3}	3.80×10^{-3}	8.00×10^{-3}
Maximum	9.50×10^{-3}	8.60×10^{-3}	5.50×10^{-2}	7.70×10^{-2}
Sample		13	15	
Minimum		7.00×10^{-3}	5.00×10^{-3}	
Median		5.10×10^{-2}	2.65×10^{-2}	
Maximum		8.70×10^{-2}	9.90×10^{-2}	

Furthermore, Fig. 3 shows a box plot diagram that indicate the value of hydraulic conductivity for pure gravel and sand mixture that consist of three different grain size with different percentage for each sediment fraction. It can be seen that from the diagram variation of hydraulic conductivity for mixture 17, 20 and 23 are smaller compared to the variation of the value for mixture 18, 19 and 21. However, hydraulic conductivity value for mixture 22 and 24 cannot be defined. Table 3 summarizes the hydraulic conductivity value for pure gravel and sand mixture consists of three ratios of different grain size.

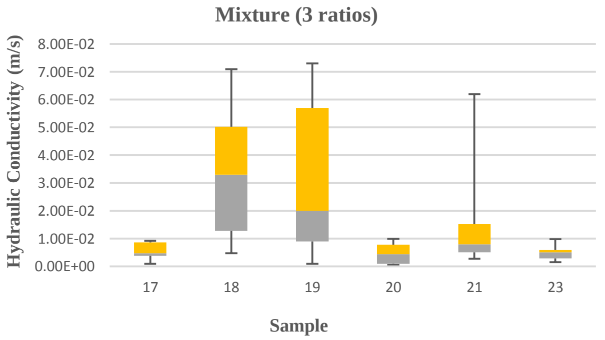

Fig. 3: Box plot diagram represents hydraulic conductivity of gravel and sand mixture (3 ratios)

Table 3: Summary of hydraulic conductivity of pure gravel and sand mixture (3 ratios)

Sample	17	18	19	20
Minimum	1.00×10^{-3}	4.80×10^{-3}	1.00×10^{-3}	5.00×10^{-4}
Median	4.80×10^{-3}	3.30×10^{-2}	2.00×10^{-2}	4.35×10^{-2}
Maximum	9.20×10^{-3}	7.10×10^{-2}	7.30×10^{-2}	9.90×10^{-3}
Sample		21	23	
Minimum		2.80×10^{-3}	1.50×10^{-3}	
Median		7.95×10^{-3}	5.10×10^{-3}	
Maximum		6.20×10^{-2}	9.80×10^{-3}	

3.3. Threshold of Grain Size Distribution and Hydraulic Conductivity

Based on the hydraulic conductivity data attained from the experiment, the threshold of grain size distribution and hydraulic conductivity were established.

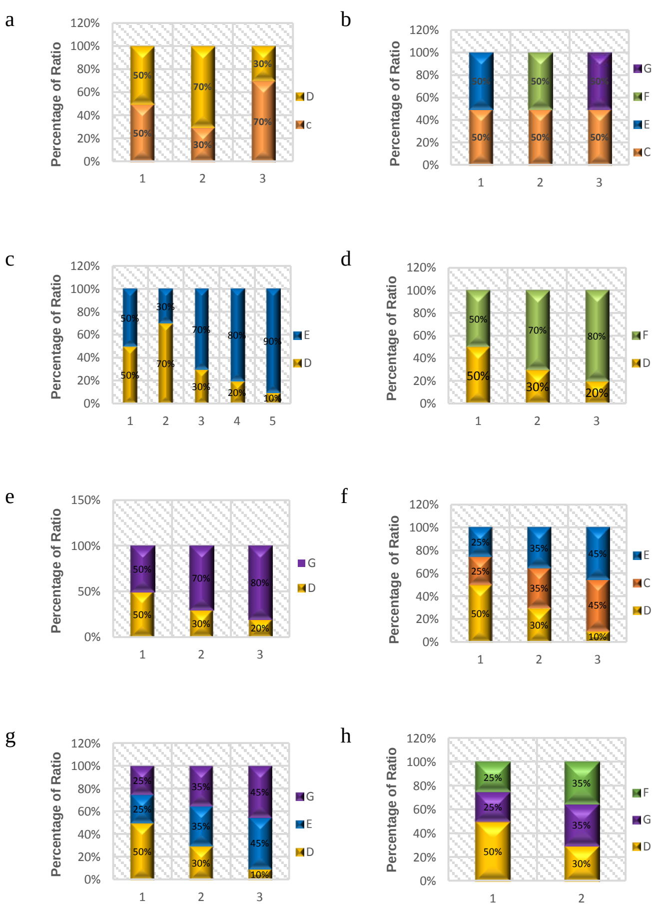

Fig. 4: Different ratios of mixture with grain size of 0.25 to 0.5 mm (A), 2.0 to 3.5 mm (B), 1.0 to 2.5 mm (C), 0.1 to 0.5 mm (D), 2.5 to 5.6 mm (E), 10 mm (F) and 6.3 mm (G)

Fig. 4(a) demonstrates the mixture with different proportions of grain size from 1.0 to 2.5 mm (C) and 0.1 to 0.5 mm (D). From the measurement that have been carried out, it shows that when the percentage of grain size D is 70% and C is 30% the value of hydraulic conductivity is slightly smaller compared with the evenly ratio. This is because of the increasing amount of smaller particle. However, when the percentage is the other way around, the value of hydraulic conductivity for the mixture cannot be defined. The reason is because of the percentage of coarser particle is higher compared to the two previous mixtures. This lead to bigger pore spaces between the particles therefore, water runs through it too fast and the hydraulic conductivity cannot be determined with this method. Whereas Fig. 4(b) shows different ratios of mixtures with grain size 1.0 to 2.5 mm (C), 2.5 to 5.6 mm (E), 10 mm (F) and 6.3 mm (G). Based on the data obtained from the measurement, when the amount of grain size C is even with the other grain size, which are E, F and G, the value of hydraulic conductivity for these three mixtures cannot be defined. This is due to the large amount of coarser particle in one mixture. Thus, the device cannot calculate the hydraulic conductivity value.

Furthermore, Fig. 4(c) indicates the mixtures with different ratios of grain size from 0.1 to 0.5 mm (D) and 2.5 to 5.6 mm (E) which grain size D is finer comparable to grain size E. From the measurement, it can be realized that the hydraulic conductivity value for the mixtures are increasing with the rising percentage of grain size E. For instance, when the percentage of grain size D is 20% and E is 80%, as expected the hydraulic conductivity value is higher compared to the value of hydraulic conductivity when the percentage of grain size D is 30% and E is 70%. Nevertheless, when the percentage of grain size E became 90% and grain size D is only 10%, the hydraulic conductivity cannot be determined. Meanwhile Fig. 4(d) shows different ratios of mixtures with grain size 0.1 to 0.5 mm (D) and 10 mm (F). The first bar in the figure displays even ratio of the sediments. While for the next bar, the percentage of grain size D was reduced to 30% resulted in significantly increased of the hydraulic conductivity value. On the other hand, when the percentage of grain size D was further reduced to 20% and the percentage amount of grain size F were 80% the value of hydraulic conductivity for the mixture cannot be attained. Grain size F were coarser than grain size D, when there is a small amount of fine particles this will lead to bigger pores between the particles and that was the reason why the hydraulic conductivity cannot be calculated.

Besides that, Fig. 4(e) shows the mixtures with different ratios of grain size 0.1 to 0.5 mm (D) and 6.3 mm (G). From the measurements that have been carried out, it can be seen that when the percentage of grain size D were reduced until 20% the hydraulic conductivity value cannot be determined. While for a mixture that consist 30% of grain size D and 70% of grain size G, the value of hydraulic conductivity considerably increased compared to the value with evenly mixed of the grain size. Nevertheless, in contrast to the mixtures in Fig. 4(d) the hydraulic conductivity value is lower because of mixtures in Fig. 4(e) contain large amount of fine particles. Furthermore, instead of two ratios of grain size Fig. 4(f) shows different ratios of mixtures with grain size 1.0 to 2.5 mm (C), 0.1 to 0.5 mm (D), and 2.5 to 5.6 mm (E). The first bar in the figure comprises 50% of grain size D, 25% of grain size C and 25% of grain size E. For the next bar, the percentage of grain size D reduced to 30%, while for grain size C and E increased by 10%. Whereas for the third bar, the percentage of grain size D further reduced to 10% and increased another 10% for both grain size C and E. This resulted in significantly increased of hydraulic conductivity according to decreasing percentage of grain size D.

Moreover, Fig. 4(g) indicates a mixture with different ratios of grain size 0.1 to 0.5 mm (D), 2.5 to 5.6 mm (E) and 6.3 mm (G). Mixtures in this figure comprise a large amount of coarser particles compared to the mixtures in Fig. 4(f) which explains the higher value of the hydraulic conductivity. Nevertheless, when the percentage of grain size D further reduced to 10% while both grain size C and E were 45% the hydraulic conductivity value cannot be obtained. This is due to small amount of finer particles in the mixture and lead to bigger pore spaces. Meanwhile, Fig. 4(h) shows different ratios of mixture with grain size 0.1 to 0.5 mm (D), 6.3 mm (G) and 10 mm (E). The first bar in the bar chart specify the mixture that contain 50% of grain size D, 25% of grain size G and 25% of grain size F. However, by only reduce the percentage of grain size D to 30% the hydraulic conductivity of the mixture cannot be determined. This is because of the additional percentage of coarser particle compared to the first mixture. Table 4 shows the summary of hydraulic conductivity value for different mixtures of pure gravel and sand.

Table 4: Summary of hydraulic conductivity value for different mixture of pure gravel and sand

Sediment 1		Sediment 2		Sediment 3		K_S
C	50%	**D**	50%			4.99×10^{-3}
C	30%	**D**	70%			6.17×10^{-3}
C	70%	**D**	30%			Not defined
C	50%	**E**	50%			Not defined
C	50%	**F**	50%			Not defined
C	50%	**G**	50%			Not defined
D	50%	**E**	50%			9.93×10^{-3}
D	70%	**E**	30%			6.23×10^{-3}
D	30%	**E**	70%			5.13×10^{-2}
D	20%	**E**	80%			2.85×10^{-2}
D	10%	**E**	90%			Not defined
D	50%	**F**	50%			7.41×10^{-3}
D	30%	**F**	70%			1.28×10^{-2}
D	20%	**F**	80%			Not defined
D	50%	**G**	50%			4.10×10^{-3}
D	30%	**G**	70%			3.75×10^{-3}
D	20%	**G**	80%			Not defined
D	50%	**C**	25%	**E**	25%	4.65×10^{-3}
D	30%	**C**	35%	**E**	35%	3.31×10^{-2}
D	10%	**C**	45%	**E**	45%	3.23×10^{-2}
D	50%	**E**	25%	**G**	25%	3.30×10^{-3}
D	30%	**E**	35%	**G**	35%	1.14×10^{-2}
D	10%	**E**	45%	**G**	45%	Not defined
D	50%	**G**	25%	**F**	25%	4.42×10^{-3}
D	30%	**G**	35%	**F**	35%	Not defined

4. Conclusion

From the results of this study, the threshold of grain size distribution and hydraulic conductivity for the laboratory sample were obtained. However, the threshold determined cannot be generalized as it also depends on the mixture of the samples. Furthermore, the device which is KSAT device used to determine the hydraulic conductivity values for the samples seems not suitable to measure the values of hydraulic conductivity especially for the Gravel. This is because the maximum size of gravel used for this study is 10 mm while the sample ring for the device is small. Therefore, it is recommended to use bigger column size due to make an enhancement of the result. Moreover, the work presented for this study can be extended by analysing bigger sets of data, providing a higher degree of reliability. To conclude, the established formula is not suitable in order to determine the hydraulic conductivity for gravel and sand mixtures.

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