Backfilling Filter Deployment for Groundwater Monitoring Well

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Abstract. This study composed the well-known criteria to design the grain size distribution of backfilling filter for groundwater monitoring well (GMW) under the sand and gravel layer. With an assumption of linear logarithmic scale distribution from D_{10} to D_{90}, the coefficient of uniformity C_u can be formulated for D_{10}, D_{60}, and D_{90} corresponding to D_{15}. Then, D_0 and D_{100} can be obtained by linearity relationship. The method of backfilling filter deployment was then demonstrated by a practical application, which validates the procedures of existing and new backfilling filter design.

Introduction

The groundwater monitoring well (GMW) is an important facility to measure groundwater level, pore pressure, and quality of groundwater, etc. The gradation of backfilling filter is one of significant factors to affect the GMW performance. The backfilling filters are known as the medium materials between the well pipe and surrounding ground layers to smooth the flow of groundwater and protect the soil layers under ground while the monitoring well is piped. An improper deployment will induce fine materials of surrounding ground layer to flow backward into the GMW, so as to decrease the accuracy of measurement and increase the load of maintenance. In order to evaluate the functionality of GMW, the past studies suggested the criterion by $D_{15}/D_{85} \leq 4$ [1], or, the filter opening with D_{15} for particle size about $D_{15}/9$ [2]. Thus the allowable pore of filter was observed as $D_5/4$ and $D_{15}/5$ and the relationship was between D_5 and D_{15} [3]. The filter pack design is purposeful to remain the fine-grained soils on the opening surface of the filter so that the dimension of filter opening must be smaller than the indicative particle size (d_I) of surrounding soil [4]. However, it is impossible for inhomogeneous filter grains to determine the opening size according to their diameters, but by using the indicative filter size D_I. Therefore, D_I and d_I are the main parameters of the criteria in the field of backfilling filter study. In this study, we proposed a modified deployment method of backfilling filter by following the filter grain deployment procedure based on the typical criteria and theoretical analysis. The results can be referred for backfilling filters into the groundwater monitoring well.

Criteria Review

Based on the criteria approved by the U.S. Soil Conservation Service (SCS) [5] bureau, a series of filter design steps can be summarized below.

Step (1): Draw the distribution curve of grain size for the soil samples in the field.

Step (2): If coarse-grained soils (no passing through the #4 sieve i.e., the grain diameter is greater than 4.75mm) exist, we modify the distribution curve by a modified coefficient below. After the modification, the materials passing through the #4 sieve are 100%.

(a) Modify the fineness modulus that is the percentage of grains passing the #4 sieve divides 100;
(b) Multiply the retention ratio (RR) of sieves smaller than the #4 sieve by the coefficient in (a);
(c) Redraw the grain size distribution curve due to the modified coefficients above;
(d) Determine the percentage of the grains passing through the #200 sieve (0.075mm) based on the curve redrawn in (c).

Step (3): Classify base-grained soils based on the ratio of passing through the #200 sieve. The four categories can be determined by (>85%), (40~85%), (15~39%), and (<15%) in order.
Step (4): Determine the allowable filter grains based on the maximum grain size D_{15} due to Table 1. Note that D_{15} is not necessary to be less than 0.2mm.

Table 1 – Criteria of filter grain classification

Category	Soil Contents	Criteria	Annotation
1	Fine silt, Clay	$D_{15} \leq 9d_{85}$	If $9d_{85}<0.2$mm then $9d_{85}=0.2$mm
2	Sand, Silt, Silt-sand, Clay-sand	$D_{15} \leq 0.7$mm	
3	Silt-sand, Clay-sand, Gravel-soil	$D_{15} \leq (40-A)/(40-15) \times (4d_{85}-0.7\text{mm})+0.7\text{mm}$	A = percentage of modified grains passing through the #200 sieve. If $4d_{85}<0.7$mm then $4d_{85}=0.7$mm
4	Sand, Gravel	$D_{15} \leq 4 \times d_{85}$	d_{85} is based on the grain size distribution without modification

Furthermore, the size of backfilling filter should reach the following demands:
(a) The maximum grain size of backfilling filter cannot exceed 75mm;
(b) The maximum percentage of grains passing the #200 sieve cannot exceed 5%.
(c) The plastic index should be 0 for the grains passing #40 sieve based on ASTM-D-4318 code;
(d) D_{15} should be in the range of 0.1mm and $4 \times d_{15}$ for infiltration.

Step (5): Herein, the good-quality gradation curve with uniform grain size distribution is required for avoiding dispersal particles. The curve should be smooth without impulse that implies some specific grain size is absent. Table 2 suggests the limitation of D_{10} and D_{90}.
Step (6): Design the opening dimension of the pipe. When the filter grains close to the opening, the diameter of the opening or the width of the gap should be smaller than d_{85}. When reverse flow occurs (from opening toward soil), the opening size must be greater than d_{15}.

Table 2 Suggested D_{10} and D_{90}

Minimum D_{10} (mm)	Maximum D_{90} (mm)
<0.5	20
0.5~1.0	25
1.0~2.0	30
2.0~5.0	40
5.0~10	50
10~50	60

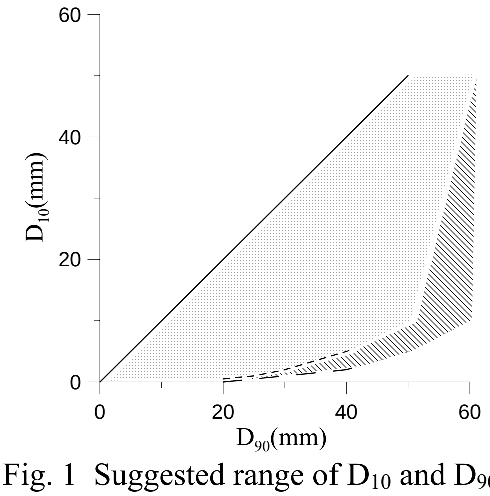

Fig. 1 Suggested range of D_{10} and D_{90}

Deployment method of backfilling filter material in groundwater monitoring well

For determining the most proper grain size, we further improve the filter grain deployment as follows by referring the regular criteria [2][5][6][7][8].

A. Maximum and minimum of allowable D_{15}

According to Table 1, we are interested in the category 4 that contains the sand and gravel which are distributed in the aquifer for the GMW. Hence the maximum D_{15} is obtained; i.e., $D_{15} \leq 4d_{85}$. Furthermore, Bertram [6] suggested a distribution range: $(D_{15}/d_{85}) < 4\sim5 < (D_{15}/d_{15})$. In which, d_{85}

and d_{15} represent the grain sizes passing 85% and 15% finer by weight, respectively, for sieve analysis of base-soils. This formulation yields the range of D15 and can be written as $4d_{15} \le D_{15} \le 4d_{85}$. Herein, the both limits imply the maximum and minimum D_{15}.

B. Determination of D_{10} and D_{60}

D_{10} and D_{60} are known to determine the coefficient of uniformity C_u (=D_{60}/D_{10}). A high C_u may cause dispersal particles because of different sedimentation velocity of grains. Therefore, the maximum C_u must be properly estimated. Referring the criteria, U.S. Army Corps of Engineers [7] and U.S. Army *et al.* [8] had defined $Cu \le 20$ as official code; Sherard *et al.* [2] suggested C_u=6 due to experiment formula since practically the coarse grains of the #4 sieve should be less than 60%. We hence consider these two criteria in this study for improvement. With assumption of linear logarithmic distribution between D_{10} and D_{60}, the equation below can be formulated.

$$(\log D_{15} - \log D_{10})/5 = (\log D_{60} - \log D_{15})/45 \text{ or } D_{60} = D_{15}^{10}/D_{10}^{9} \quad (1)$$

Substitute C_u into Eq. (1), we can estimate both D_{10} and D_{60} if D_{15} is known.

$$D_{10} = D_{15}/C_u^{0.1} \quad \text{and} \quad D_{60} = C_u^{0.9} D_{15} \quad (2)$$

C. Determination of D_{90}

In order to avoid dispersal particles, the relationship of D_{10} and D_{90} shown in Table 2 can be coordinated in Fig. 1. Herein, we adopt the distribution located within the light-gray region of the diagram thus the extreme value distributed in the dark-shadow region is not suggested. Similarly, we assume the grain size between D_{10} and D_{90} distributing as linear logarithm, then

$$\frac{\log D_{15} - \log D_{10}}{5} = \frac{\log D_{90} - \log D_{15}}{75} \text{ or } D_{90} = C_u^{1.5} D_{15} \quad (3)$$

Due to eq. (3), D_{90} is acceptable if the outcome can satisfy the requirement in Fig. 1.

D. Determination of D_0 and D_{100}

Considering extrapolation to linear distribution for D_0 and D_{100}, in which $D_0 \ge 0$, we have

$$(D_{10} - D_0)/10 = (D_{15} - D_{10})/5 \text{ or } D_0 = 3D_{10} - 2D_{15} \quad (4)$$

$$(D_{100} - D_{90})/10 = (D_{90} - D_{60})/30 \text{ or } D_{100} = (4D_{90} - D_{60})/3 \quad (5)$$

E. Dimensionless distribution curve of grain size

By following steps above, once we are able to determine D_{15}, D_{10}, D_{60}, D_{90}, D_0, and D_{100} in order, the distribution curve of filter grains can be drawn by dividing all grain sizes into D_{15}. Fig. 2 displays the diagrams of dimensionless distribution curves of various filter grain sizes according to classification in Table 1. Wherein, the coefficient C_u=1 stands for uniform grain size that can perfectly avoid dispersal particles but yield high cost. The coefficient C_u=20 presents the upper limit that could cause the dispersal phenomenon and lead grained soils to silt up the GMW. Therefore, the coefficient C_u=6 provides a conservative estimation for design. However, the calculation of D_{90} in Eq. (3) could exceed the upper limit of D_{90} limited in Fig. 1. Therefore, D_{90} should be revised by using the upper limits, as shown in Fig. 2(b), which the curve of C_u=20 is arranged between the area bounded by D_{60} and D_{100} and is mapping to Fig. 1. Similar conditions of D_{90} and C_u=20 are found in Fig. 2(c) to (f) so that the lower C_u (e.g. C_u=5.5 in Fig. 2(f)) is suggested to match the criteria.

Application of deployment method

As considering the base-soils, the result of sieve analysis is shown in Table 3. The soil is classified into category 4 since 10% of soils can pass through the #200 sieve. Meanwhile, it is easy to obtain d_{15}=0.093mm and d_{85}=0.387mm of the base-soils due to the distribution diagrams. Based on the range of D15, we can carry out both limits of the D_{15} grain size within $0.371\text{mm} \le D_{15} \le 1.51\text{mm}$. Then, we assumed two possible approaches to determine the backfilling filter: (1) validate the usefulness of existing filter; and (2) design a qualified filter.

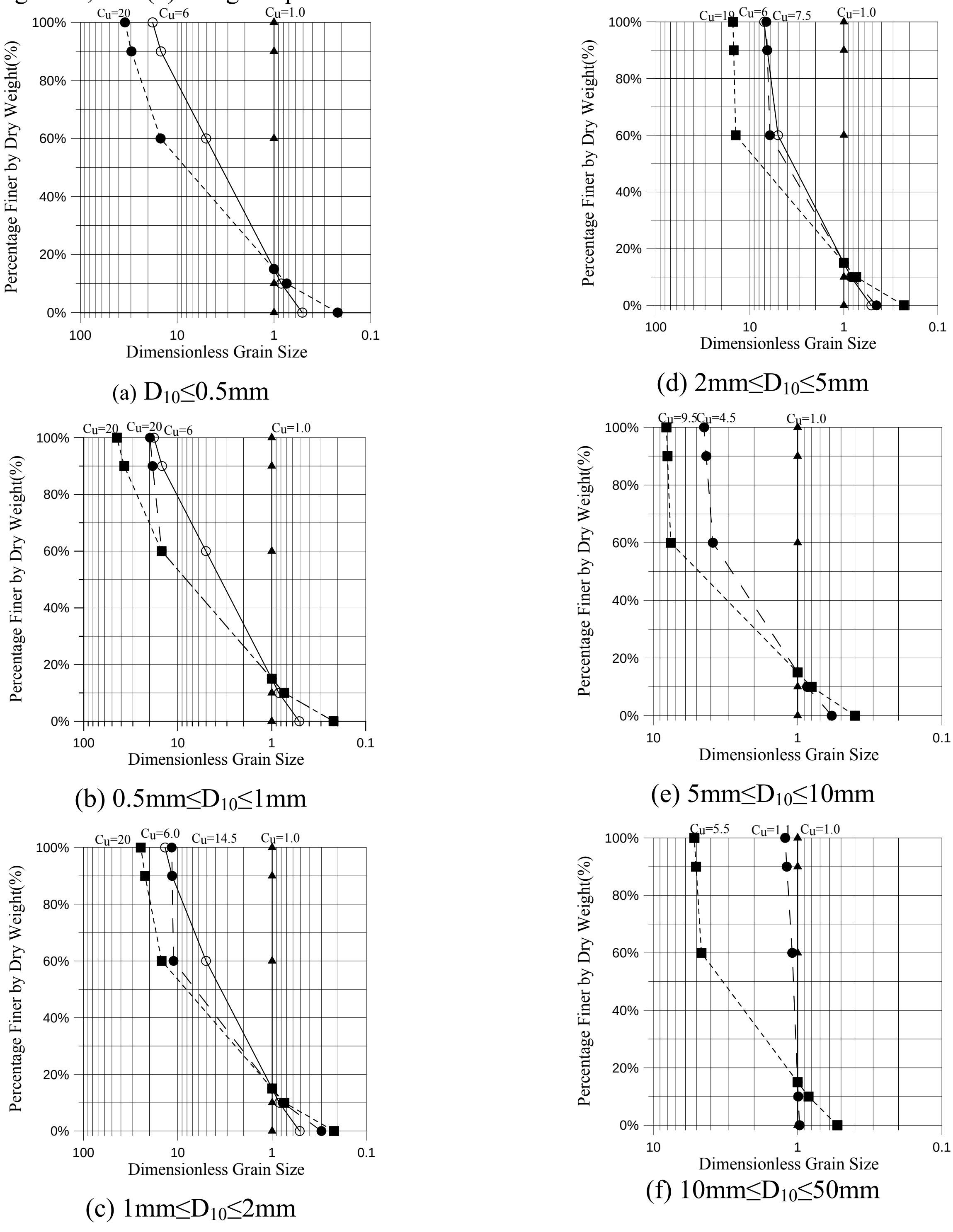

Fig. 2 Dimensionless distribution of D_{10}

A. The sample filter validation

Moreover, we selected a backfilling filter sample, and the result of sieve analysis is shown in Table 3. We can then substitute the data into equations and check if the sample can match the criteria. The computation gives D_{10}=0.5mm, D_{15}=0.6mm, D_{60}=3.01mm, and D_{90}=4.32mm, in which D_{15} is between 0.371mm and 1.51mm and satisfy the criteria. As considering the coefficient of uniformity C_u, we obtain both of D_{60}/D_{10}=6 and D_{90}/D_{10}=8.64 to approach all given diagrams above. Therefore, the sample is qualified for filter backfilling and the dimensionless distribution curve of grain size is located within the bounds shown in Fig. 3.

B. The sample filter design

On the other hand, instead of criteria, we can also deploy the sample filter with given D_{10}, D_{15}, D_{60}, and D_{90} above by using derivative equations in previous section. Adopting the sample filter with D_{15}=0.6mm and C_u=6, we have $D_{10}=D_{15}/C_u^{0.1}$=0.5mm and D60=$C_u^{0.9}D_{15}$=3.01mm by Eq. (2). Thus, D_{90} can be calculated as $C_u^{1.5}D_{15}$=8.82mm by Eq. (3). In practical, we may consider D90=4.32mm, for comparison with previous computation, and carry out D_0=0.18mm and D_{100}=4.76mm due to Eq. (4) and (5), respectively. Now we can compare both results obtained by criteria or formulation and plot the distribution curve of gradation shown in Fig. 4, where the distributions are almost identical.

Table 3 – Sieve analysis of base-soils and the sample filter

		Base Soils		Sample Filter	
Sieve no.	Grain size(mm)	Retention (%)	Passing (%)	Retention (%)	Passing (%)
	0	10	0	0	0.0
200#	0.074	20	10	0	0.0
100#	0.149	25	30	2.1	0.0
60#	0.25	40	55	5.3	2.1
40#	0.42	5	95	12.1	7.4
20#	0.841		100	21.6	19.5

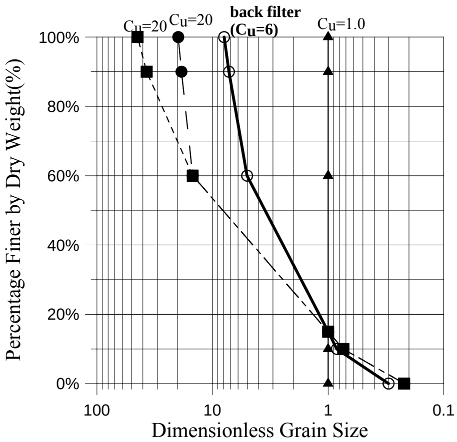

Fig. 3 Comparison between the sample filter and the criteria for 10mm≤D_{10}≤50mm

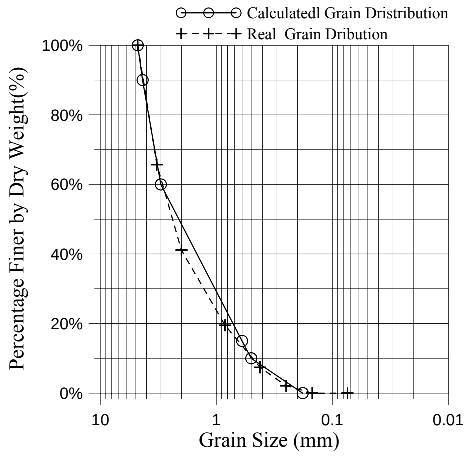

Fig. 4 Comparison for the gradation distribution of filter by criteria and formulation

Summary

This study reviews well-known standards of filter grain sizes and design the appropriate criterion for the deployment of filter backfilling for the groundwater monitoring well. The criterion includes the upper and lower limits of the filter grain size D_{15}, the range of the coefficient of uniformity C_u, and formulation of grain size D_{10}, D_{60}, D_{90}, D_0, and D_{100} upon the assumption of the linear logarithmic distribution corresponding to C_u and D_{15}. The use of these parameters is described and validated by the practical experiment.

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