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地下水監測井過濾料與土壤顆粒分佈關係

Grain Distribution Relationship between Backfill Filter of Groundwater Monitoring Well and Soil Type

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Author

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摘 要

本研究建立地下水觀測井回填濾料粒徑分佈，濾料主要用途為防止基礎土壤中之坋粒及黏粒沖蝕，也就是說濾料組成決定於基礎土壤中坋粒及黏粒之比例。因此，本研究製備了 6 種土壤樣品，分別為 10％，20％，30％，50％，70％和 90％的土壤通過＃200 篩。回填過濾料的粒徑分佈設計依循 Hong et. al.(2011)之設計。隨後進行 Proctor 壓實試驗，用於模擬地下基礎土壤的壓力條件，以找到最佳含水量。然後通過無沖蝕濾料試驗，並施加高地下水壓力以測試回填濾料設計。試驗的結果據以修正地下水監測井之回填濾器料設計，並找出適用於各類土壤之回填濾料粒徑分佈。

關鍵詞：地下水觀測井、無沖蝕濾料試驗、回填濾料

ABSTRACT

This study established the grain size distribution of backfill filter for groundwater monitoring well. Backfill filter is used to prevent the erosion of base soil such as silt and clay. i.e. Formation of backfill filter is determined by the ratio of silt and clay within base soil. Therefore, 6 types of soil sample were prepared with percentage of 10%, 20%, 30%, 50%, 70% and 90% of soil passing through the #200 sieve. Grain size distribution of Backfill filter can be obtained by Hong et. al. (2011). Proctor compaction test, which was used to simulate the pressure condition of base soil under the ground was executed to find Optimum Moisture Content (OMC). The design method of backfill filter is then tested by No Erosion Filter Test (NEFT), which is adopted to deploy filter grains to prevent piping when the high groundwater pressure applies on the crack. Results of these test can be referred for backfilling filters design method into the groundwater monitoring well and to find the suitable grain size distribution of backfill filter for lower and upper limit of D_{15} (diameter smaller than 15% filter grain size) on various soil type.

Keywords: Groundwater Monitoring Well, No Erosion Filter Test, Backfill filter.

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LIST OF ABBREVIATION

Symbol	Explanation	Unit
C_u	Coefficient of Uniformity	-
k	Permeability coefficient	$[LT^{-1}]$
PI	Plasticity Index	%
d_n	Size of base soil materials of which n percent of the material passes	[L]
D_i	Filter particle diameter with i% finer by mass	[L]
D_{15b}	No erosion boundary filter size resulting from an NEF test on a base soil	[L]
C_c	Clay content; percentage finer than 0. 005 mm in the adjusted gradation	%
F_c	Fine content; percentage finer than 0. 075 mm in the adjusted gradation	%
M_c	Silt content; percentage between 0. 005 mm and 0. 075 mm in the adjusted gradation	%
A_r	Activity ratio	-
P_r	Passing ratio from #200 sieve	%

Chapter 1 Preface

1.1 Introduction

A well with small diameter drilled into the ground in order to measure the water level under the soil as well as the pore pressure and the quality of ground water. This well known as Groundwater monitoring well(GMW). This well have great importance to maintain the check regarding the water under the soil. There are several ways to drill the well or types of well depending on the composition and types of soil where the well is drilled. The main component which ensure the longer life of well is the filter pack material which is placed on the surrounding of the hole while well is drilled. This filter material allows smooth flow of water and prevent fine material to flow backward into the well. It also prevents piping in the soil which result in sudden breakdown of the structure.

The proper deployment of filter grading is one of significant factors to affect the GMW performance. Improper deployment of filter will result in fall of fine grain backward into the GWM. Numerous filter design criteria have been proposed, among which the criteria presented by Sherard and Dunnigan [1985,1989] are broadly implemented in modern dam. The recent study about filter design by Hong et. al. (2011) have the better equation and can apply on wide range of soil. It not only provides the range of D_{15} but also the value of D_{10}, D_{60}, D_0, D_{100}, and D_{90}. So it become easy to make the filter sample with all these values. This study used the equation developed by Hong et. al.(2011) to make the filter sample and checked the success of sample against the No Erosion Filter Test (NEFT). But unfortunately range of D_{15} is quite large hence this study trying to reduce the range of D_{15}.

1.2 Objective

The main objective of this research is to do the different types of soil test on different types of soil. Using the result of this test to do the No Erosion Filter Test. Which ultimately help to find the best possible grain size distribution of filter particle. It can be used to prevent outer fine soil particle to go inside the groundwater monitoring well so that life span of well become longer and also the smooth flow of water inside the well.

The compaction test done on different range of soil so that a general trend can be set to find the result of the compaction test of any types of soil without doing the real experiment. Several research has been done for proposed filter criteria but this research using the data and idea of previous research to reduce the range of the grain size. This grain size distribution can be used to prepare filter for the groundwater well to ensure the safety and long life of well.

This research also studies about the permeability of different types of soil which can be used to predict the nature of soil about the consolidation. A general trend also found out for the permeability value of different types of soil. And standard deviation of the result will also be find out to know the accuracy of the result. The trend line can also be used to find permeability of any types of soil without the real experiment.

This research covers the all possible varieties of soil ranges from 10% to 90% of soil passing through #200 sieve. So it will be easy of find the result of any test for any soil in real case. To find the value of any test initially sieve analysis is to be done and to check the types of soil and percentage passing through #200 sieve then this result can be used to find result of any test by interpolation or from the graph.

Chapter 2 Literature Review

2.1 *Introduction of filter test*

Earlier filter test for silt and clay had two different kinds. One was slot test and other slurry test. Both test gives similar result in general (Sherard et al. 1984b). For both tests, there is a little sum of disintegration of the base. During this test "no visible erosion" of the walls of the preformed leakage channel took place. A test was judged to be successful when the stream rate quickly diminished and stabilized with a little steady stream of clear water. Later another test was adopted in which it was possible to define a filter boundary size, D_{15b}. A visible erosion can be seen for filters slightly coarser than the boundary. No erosion filter (NEF) test, was also found to work very well for coarse-grained impervious soils. whereas the slot and slurry tests do not give satisfactory result for impervious soils with d_{85} size much greater than about 0.1 mm.

2.1.1 Types of filter tests

There are several types of filter tests as following:

(a) Conventional test

Base soil is compacted on the filter material without a hole through the base sample; generally used for cohesionless base soils (Kenney et al.1984; Sherard et al. 1984a)

(b) Base suspension test

Base soil is mixed with water to produce a suspension that is passed through the filter (Kenney et al. 1984)

(c) Slot test

Base soil is compacted on the filter material; a slot is formed through the base soil through which water is passed (Sherard et al. 1984b)

(d) Slurry test

Base soil is mixed with water to form a slurry about the same consistency as motor oil; the slurry is placed over the compacted filter material and water pressure is applied (Sherard et al. 1984b)

(e) No erosion test

This method was developed by Sherard and Dunnigan (1989), similar to slot test but the preformed hole is a 1-mm-diameter hole punched through the base specimen.

2.1.2 Statistical analysis of filtration tests

Statistical analysis of filtration tests was completed by Honjo and Veneziano (1989), who studied 287 filtration tests, mostly on cohesionless base soils with 0–25% fines content. The result of this test is that the ratio D_{15}/d_{85} is the most significant factor of filter performance for cohesionless soils.

Fischer and Holtz (1990) studied 158 filtration tests on different varieties of soil and suggested that the D_{15}/d_{75} ratio accurately predicts granular soil retention behaviour, whereas the filter Cu is not useful in predicting the filtration performance.

Foster and Fell (2002) studied a large database, including all types of filtration test: ‘conventional’, ‘slurry’, ‘slot’ and NEF on approximately more than 700 sample which resulted in credible results.

Delgado Ramos et al. (2010) also analysed group 1 and 2 base soils using the database of Foster and Fell in addition to 272 NEF tests conducted by Delgado Ramos. In general, the filtration databases cited have the following characteristics.

(a) Different types of filtration test (such as conventional, slurry, slot and NEF) analysed.

(b) All test results (successful, unsuccessful and intermediate) are analysed.

(c) Both base soil and filter characteristics are included in the analysis.

Delgado Ramos et al. (2006) conducted filtration tests on large scale on group I and group II base soils. Total 688 tests were investigated among them 492 were NEF tests (105 tests conducted by Sherard and Dunnigan (1985, 1989), 47 tests reported by Foster and Fell (1999) and 340 performed by Delgado Ramos et al. (2000). Similar to the work of Foster and Fell (1999), Delgado Ramos et al. (2006) focused on determining boundaries condition between unsuccessful and successful base soil/filter behaviours. In addition, Delgado Ramos et al. (2006, 2016) suggested considering filter permeability in filter design. However, Fell et al. (2015) discouraged this idea because measuring and controlling filter permeability is generally difficult in practical engineering problems.

Shourijeh and Soroush (2009) collated a large number of filtration data base. Among them generally there were two different categories present. (a) only NEF tests were considered, excluding other test for filtration, and (b) a 'no-erosion' boundary filter and its associated D_{15b} were considered for each base soil. By definition the boundary filter, D_{15b} is the D_{15} of the coarsest filter that prevents erosion in NEF testing (i.e. leads to no erosion for the base soil). A total of 152 group I and group II base soils and the corresponding D_{15b} values determined through NEF testing were studied by Shourijeh and Soroush (2009). This work was founded on the proposition by Sherard and Dunnigan (1989) that 'the filter boundary D_{15b} can be considered a property of the base soil in the same sense that results of tests to determine the

Atterberg limits and effective shear strength parameters are considered properties of the impervious soil.

2.2 *Importance of Filter*

Two major causes of failure in earth dams are Internal erosion and piping, which contribute almost 50% of all failures; the other major cause is overtopping (Fell and Fry, 2007; Flores-Berrones et al., 2010; Foster et al., 1998; ICold, 2013; Minguez et al., 2006). Internal erosion and piping can be avoided through good design and close supervision during construction, especially of the core. Thus the selection of an appropriate filter in protecting a core has become critical. Foster and Fell (1999) have found four sequential phases involving erosion that lead to failure of an earth dam.

(a) Initiation of erosion (when leaks set out through cracks in the core).

(b) Continuation of erosion (in the presence of inappropriate filter material protecting the core). Foster and Fell (2001) further indicate that the possibility of erosion continuing in a dam is influenced by the particle size distribution (PSD) of both the base soils that make up the core and the filter materials that are protecting the core.

(c) Progression of piping (i.e. enlargement of erosion channels running through the core).

(d) Formation of a breach mechanism (i.e. the untimely culmination of failure due to piping progression).

Consequently, settlement of the crest and instability of the downstream slope could occur (Fell et al., 2003).

2.3 Filter design criteria

A special attention is required in the filter design stage, where the selection of appropriate methods and criteria determines the performance of a filter in protecting the core and consequently the earth dam. The design of a filter can be achieved with either the direct or the indirect method. Accepting established criteria during design constitutes the indirect method, whereas carrying out actual tests, such as the no-erosion filter (NEF) test, during design constitutes the direct method. From the point of view of Goldsworthy (1990), when vigorous erosion of the core material is anticipated in the field, it is essential that the designing of filter material should be based on the direct method. The direct method has also been recommended for certain conditions, such as when the core is too slender or the upstream shoulder is too permeable.

The established filter design criteria are the combination of numerous investigations on the behaviour of filters, such as the studies by Foster and Fell (2001), Sherard and Dunnigan (1989) and Shourijeh and Soroush (2009). To cite an example, Sherard et al. (1984) have determined that a sandy filter with D_{15} = 0.5 mm is generally sufficient, even considered conservative, in protecting a core made of the finest clays, such as with d_{85}<0. 1 mm. The most prevalent filter design criteria corresponding to base soils of various grain sizes are the ones by Sherard and Dunnigan (1989) as given in Table 1.

However, certain laboratory investigations, such as the studies by Locke and Indraratna (2002) and Soroush et al. (2006) have suggested that using such criteria or the corresponding filter boundaries would not be reliable. In other words, satisfying the Sherard and Dunnigan (1989) criteria would not necessarily mean success in laboratory filter testing. Some evidence is provided as follows.

(a) The D_{15}/d_{85} = 5. 7 to 6.2 for successful filtering of low plasticity clay soils was experimentally determined through NEF tests by Sherard and Dunnigan (1989). Therefore, the filter criterion of $D_{15}/d_{85} < 9$, as stated of Table 3, cannot be exactly reliable.

(b) Some silts or clays for base soils are described as very uniform at the coarse end and having $d_{98}/d_{85} < 2$. For one such soil, the D_{15}/d_{85} value for successful filtering was experimentally determined by Sherard and Dunnigan (1989) to be in the range of 6–7.5, which is finer than stated in Table 1.

(c) Sherard and Dunnigan (1989) have emphasised that the experimentally determined filter boundaries were not influenced by or related to erosion resistance of the base soil the observations have led to such criteria. However, based on experiments, Foster and Fell (2001) have appointed a finer filter boundary for soils that are more susceptible to erosion: the dispersive soils.

(d) Locke and Indraratna (2002) carried out the NEF tests on samples of a broadly graded base soil that was categorised into group 1 and group 2 of Table 1. However, for a sample from group 2, the successful filter was one with D_{15}=0.19 mm, which is 3.7 times filter than the 0. 7 mm proposed by Sherard and Dunnigan (1989). Furthermore, for 11 samples from group 1, the values of D_{15}/d_{85} were determined to be in the range of 7.1–23.5, but for two of the samples, the achieved D_{15} were finer than proposed by Sherard and Dunnigan (1989).

(e) Based on the results of extensive NEF testing, Delgado et al. (2006) stated that filter criteria derived from permeability of a filter and PSD of corresponding base soil are more appropriate than those derived from PSDs of a filter and corresponding base soil, the latter being the criteria by Sherard and Dunnigan (1989).

So in the presence of various filter design criteria of the literature, attention should be paid as to which of these is suitable for any given base soil and the surrounding circumstances in the field.

2.4 *Summary of past research*

The previous laboratory research, theoretical studies are reviewed and summarized in tabulated form:

Table 1 Summary of past research

Investigator	Paper name	Discussion	Criteria
Arulanandan, K. (1983)	Erosion in Relation to Filter Design Criteria for Earth Dams	• Discussion of current filter design practice • Review of previous testing regarding erosion •	• Terzaghi's design criteria do not consider erodibility characteristics of fines in the base material • Dispersive / Nondispersive behaviors do not accurately quantify whether a soil is erodible
Vaughan, P.R. & Soares, H.F. (1983)	Design of Filters for Clay Cores of Dams	• 50mm diameter acrylic tube 450mm in length was set up vertically • A plug of pre-saturated filter material was compacted at the bottom of the tube	• Suggest that permeability should be the main measure of filter performance • Performed "Sand Castle" tests to determine whether or not a filter is cohesionless

Sherard, J.L., Dunnigan, L.P. & Talbot, J.R. (1984)	Basic Properties of Sand and Gravel Filters	• Filter test apparatus consisting of clear plastic cylinder with 10.16cm diameter. • Pressurized water system with approximately 4kg/cm^2 of pressure flowing through the cylinder.	• Angular particles and sub-rounded alluvial particles are both satisfactory for use as filter material. • The particle distribution of the filter material need not be the same as that of the base material.
J. L. Sherard et. al. (1989)	Critical filters for impervious soils	• Replacement of slot test and the slurry test • NEFT on different soil types • Foundation of filter boundary D_{15b}	• There is unique filter boundary, D_{15b}, for each base soil • Entire range of soil used for embankment categorized into four soil group.
Thomas harter(2003)	Water Well Design and Construction	• Determining a well location • Water well design and installation • Well drilling • Well development	• Significant barrier is important • Surface casing and well seals are particularly important. • Well efficiency and pump efficiency

Abbas Soroush et al. (2009)	Statistical study of no-erosion filter (NEF) test results	• Analysis of filtration tests • Plasticity index (PI) and Dispersivity potential result mentioned • Predictive relations for d_{15b}	• The design criterion for group 4 base soils is a linear interpolation between group 2 and 3. • Filter criteria are reliable only when applied with proficient, expert judgement.
Yao-Ming Hong et al. (2013)	The Design and Experiment of Backfill Filter for Groundwater Monitoring Well	• Designed a procedure of NEF test based on the common criteria and theoretical analysis • Drainage sediment calculated with different interval of time for different backfill filters.	• Yielded the range of D_{15} and can be written as $4d_{15} \leq D_{15} \leq 4d_{85}$. • The coefficient of uniformity (Cu<6) is suggested to avoid dispersal particles for better performance
Vakili, A. H., & Selamat, M. R. B. (2014).	An assessment of veracity of filter criteria for earth dams	• Criteria by Sherard and Dunnigan (1989) were modified. • The well-established criteria for filter design were found not always to be compatible with NEF test results.	• Perfect filtering approach was recognised as a realistic procedure for designing a filter in the case of highly dispersive soil • Criteria by Foster and Fell (2001) and Shourijeh and Soroush (2009) still be considered effective

Piltan Tabatabaie Shourijeh et al. (2017)	A parametric database study of no-erosion filter tests	• Revisiting critical filter design criteria through compilation and analysis of published NEF test results • Modification to the available criteria and guidelines for critical filter design are suggested.	• Activity ratio (Ar) may be considered as an indirect indicator of mineralogy for clay particles. • The limited data suggest that while $D_{15b}/d_{85} \leq 9$ is fairly safe in most cases, $D_{15b}/d_{85} \leq 6$ assures no erosion for all results.

Chapter 3 Theory

3.1 Theory of filter material

When the filter materials are packed closely to each other they form a mass which allow specific dimension of soil to pass through them. It can be seen through the basic layout diagram shown here. When three particle of filter are arranged closely to each other it makes a hole between them. And if the soil particle is bigger than the size of the hole then it will not be easy for soil particle to pass through them. But it allows water to pass so it help in smooth flow of water.

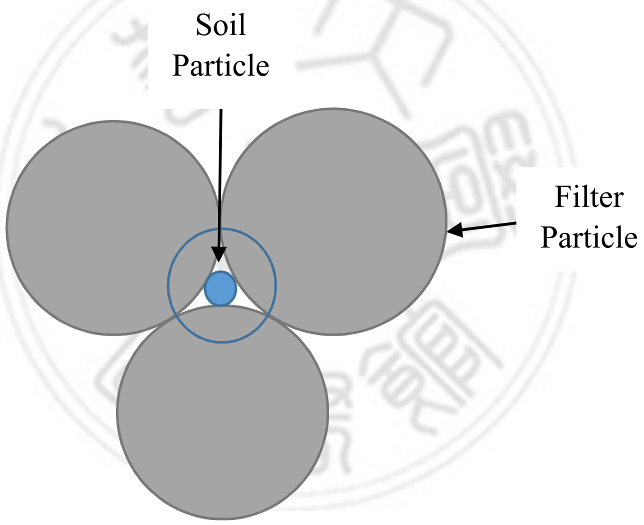


Figure 3-1 : Basic layout of filter and soil particle

3.2 Filter grain deployment

It has been found out that D_{15} is the deciding factor for the designing of filter. So many researchers have given the formula to find it for different types of soil. Among them the study of Sherard and Dunnigam (1985) and J.L.Sherard et al. (1989) are more famous and accepted by most other researchers. Their finding has been tabulated below.

Table 2. Proposed filter criteria

Investigator	Proposed Filter Criteria
Sherard and Dunnigan (1985)	• For soil group 1, $D_{15} \leq 9 \times d_{85}$, but not smaller than 0.2 mm. • For soil group 2, $D_{15} = 0.7$ mm. • For soil group 3, $D_{15} < 4 \times d_8$. • For soil group 4, $D_{15} < (40 - A/40 - 15)(4 \times d_{85} - 0.7 \text{ mm}) + 0.7$ mm
J.L.Sherard et al. (1989)	• For soil group 1, $D_{15} \leq 7d_{85} - 12\ d_{85}$ (Average $D_{15} = 9d_{85}$) • For soil group 2, $D_{15} = 0.7 - 1.5$ mm. • For soil group 3, $D_{15} <$ Intermediate between group 2 and group 4 • For soil group 4, $D_{15} < 7d_{85} - 10\ d_{85}$
Hong et. al. (2011)	For general soil $4d_{15} \leq D_{15} \leq 4d_{85}$ Assuming the linear Logarithmic distribution and Assuming a value of C_u • $D_{10} = D_{15} / C_u^{0.1}$ and $D_{60} = C_u^{0.9} D_{15}$ • $D_{90} = C_u^{1.5} D_{15}$ • $D_0 = 3D_{10} - 2D_{15}$ and $D_{100} = (4D_{90} - D_{60})/3$

U.S. Soil Conservation Service (SCS) (1986) bureau suggested $D_{15} \leq 4d_{85}$. And Bertram (1940) suggested a distribution range: $(D_{15}/d_{85}) < 4{\sim}5 < (D_{15}/d_{15})$. By combining these two Hong et. al. (2011) developed range of D_{15} and can be written as $\mathbf{4d_{15} \leq D_{15} \leq 4d_{85}}$. This can be applied with almost every types of soil. To get the value of d_{15} and d_{85} for different percentage passing from #200 sieve, sieve analysis is done and their result plotted on the graph and analyzed. From graph the value of d_{15} and d_{85} were found which represents 15% and 85% of the soil particles are finer then this size.

Firstly 6 types of soil sample were prepared with percentage of 10%, 20%, 30%, 50%, 70% and 90% of soil passing through the #200 sieve. For value of $C_u=6$ and taking the value of d_{15} and d_{85} from the result of sieve analysis of different types of soil sample, different diameter for filter particle or percent finer can be found using the formula from Hong et. al, (2011). Using this value filter sample is formed and further tested weather formed sample is successful or unsuccessful against the NEF Test.

3.3 *Different type of soil and properties*

Soil have been categorized in past into major four types according to their physical size and properties. These four types of soil properties and their past results have been summarized here:

3.3.1 Fine silts and clays

Fine silts and clays belongs to soil group 1. Base soils with more than 85% fines content (F_c), after adjustment to the maximum size of 4.75 mm, are designated in group 1. According to Sherard and Dunnigan for this group,

(a) The D_{15b}/d_{85} ranges from 7 to 12, with $D_{15} < 9d_{85}$ selected as the criterion

(b) No correlation exists between test results and relative erosion resistance, Atterberg limits or tendency to dispersive erosion

(c) For low-plasticity clays (CL-ML), the experimental D_{15b}/d_{85} is 5.7 to 6.2. Foster and Fell (1999) suggested that D_{15b}/d_{85} for group I base soils is between 6·4 and 13·5. Similarly, Shourijeh and Soroush (2009) reported that D_{15b}/d_{85} is generally in the range from 7 to 13·5, although it may be as high as 27.

(a) Fine content

There is a general trend for D_{15b}/d_{85} to increase with content of clay particles finer than 0.005 mm, that is, C_c. Clay content significantly influences the filtration behaviour of group 1 base soils. The variation of D_{15b}/d_{85} with the silt content M_C, that is, the percentage between 0. 005 mm and 0. 075 mm is that D_{15b}/d_{85} decreases as M_C increases.

Fines content (F_c) of base soils comprises clay (C_c = percentage passing 5 μm) and silt (M_c = percentage between 5 μm and 75 μm) fractions; that is, $F_c = C_c + M_c$. C_c shows a fairly normal distribution for group I base soils, with average of 41·8%. In addition, 69% of the data (114 soils) have $30\% \leq C_c < 60\%$ and hence few of the base soils in the data base are rich in clay or full of silt.

(b) Plasticity Index(PI)

Plasticity index has a positive effect on the filtration (i.e. increases D_{15b}); and cohesionless (low PI) fine-grained (small d_{85}) base soils require exceptionally fine 'no erosion' filters. a lower plasticity index results in lower erosion resistance, whereas the d_{85} size is responsible for self-filtration. Fine-grained, non-plastic/low-plastic base soils (CL-ML and ML) are troublesome from the viewpoint of filtration, since they are both highly erodible and fine grained: that is, they are easily eroded and difficult to retain.

(c)Activity ratio (A_r)

Activity ratio (A_r) may be considered as an indirect indicator of mineralogy for clay particles (Mitchell and Soga, 2005). The A_r is the ratio of PI (%) to the percentage of particles finer than 2 μm. According to Fell et al. (2013) 'The main physical parameters influencing the erosion of cohesive fine-grained soil are the particle size distribution (grain size), the clay fraction and the clay mineralogy'. unfortunately, information concerning mineralogical compositions of the base soils is mostly unavailable in the database.

(d) Dispersivity potential

For group 1 base soils, there is a general trend for D_{15b}/d_{85} to increase with increasing dispersion percentage. Sherard and Dunnigan (1989) stated that D_{15b} is not related to a tendency for dispersive erosion. Contrary to this, filtration studies – specifically those containing NEF results – state that dispersive group I base soils require finer no-erosion filters, that is D_{15b}. The criteria of $D_{15} \leq 6 \cdot 4 d_{85}$ and $D_{15} \leq 6 \cdot 5 d_{85}$ have been recommended by Foster and Fell (1999) and USBR (2011), respectively, whereas Shourijeh and Soroush (2009) suggested D15≤7·5d85. More recently, Fell et al. (2015) proposed even finer filters for dispersive group I soils complying with $D_{15} \leq 6 d_{85}$ and, through elaborate NEF tests, Vakili et al. (2015) advised $D_{15} \leq 5 \cdot 5 d_{85}$.

3.3.2 Sandy silts and clays

Sandy silts and clays belongs to soil group 2. Base soils with an original fine content (F_c) of 40–85%, after adjustment to the maximum size of 4. 75 mm, are categorised in group 2. According to Sherard and Dunnigan, for group 2 base soils: (a) the material behaviour in the NEF test is essentially the same as group 1, since sand particles are surrounded by the dominant fine matrix and thus play no role in filtration; (b) no correlation exists between the D_{15b} values and the base soil's gradation characteristics; (c) the experimentally deified D_{15b} generally ranges from 0.7 to 1. 5 mm, with D_{15} < 0. 7 mm as the design criterion.

(a) Variation of D_{15b} with d_{85}

The frequency variation of d_{85} for group 2 base soils is highly biased to finer/smaller d_{85} sizes (note that the standard deviation (s) is higher than arithmetic mean (m_a)). This means that, that in dealing with group II base soils, designers/specialists were commonly inclined towards selecting finer base soil gradations close to group 1.

(b) Fine content

Shourijeh and Soroush (2009), group 2 base soils with a high fines content imparts behaviours similar to group 1 bases; hence, D_{15b}/d_{85} might better represent their no-erosion boundary. Subsequently, Shourijeh and Soroush proposed that, for group 2 base soils with $F_c \geq 80\%$, D_{15b} should be selected as 0·7 mm or $6{\cdot}4d_{85}$, whichever is the smaller.

(c) Plasticity Index(PI)

It is apparent that group 2 base soils have lower PIs than group 1 soils due to their lower Fc and, in turn, higher Sc. Moreover, 83% of the data (note that N = 70) have PI < 20%, corresponding to lean clays/silts with sand. for sandy soils, an increase in PI is generally less influential in depleting erodibility in comparison with fine silts and clays (Fell et al., 2013).

(d) Dispersivity potential

Foster and Fell suggest that, for highly dispersive group 2 base soils (pinhole classification D1 or D2 or Emerson class 1 or 2), $D_{15b} < 0.5$ mm deifies the no-erosion filter.

3.3.3 Sands and gravels

Sands and gravels belongs to soil group 3. Sherard and Dunnigan define the design criterion as $D_{15}/d_{85} < 4$, and imply that d_{85} is obtained from the original base-soil gradation, since sand and gravel particles are dominant in the soil fabric and contribute in filtration. In the authors' opinion, as in some filter design guidelines, 4 d_{85} should always be acquired from the adjusted gradation curve, even for group 3 base soils.

Analysis by Foster and Fell showed that, for this group, D_{15b}/d_{85}= 6.8–10. This accords well with Sherard and Dunnigan's assertion that D_{15b}/d_{85} = 9 or 10 for materials with angular grains and D_{15b}/d_{85} = 7 to 8 for materials with rounded grains.

3.3.4 Clayey and silty sands

Clayey and silty sands belongs to soil group 4. Base soils with 15–35% fine content (in the adjusted gradation) are considered as group 4. The design criterion for group 4 base soils is a linear interpolation, based on the fine content between the design criteria of groups 2 and 3. In general, D_{15b} is considerably higher than D_{15} from interpolation. Note that the interpolated D_{15} was calculated using d_{85} of the adjusted gradation curve. For group 4 base soils, sand particles contribute to the filtration process. To investigate this, the variation of D_{15b}/d_{85} with sand content (particles between 0. 075 mm and 4. 75 mm in the original gradation curve). Hence as the sand content increases, D_{15b}/d_{85} increases.

Chapter 4 Laboratory experiment

In order to start the No Erosion Filter Test with any sample of soil there are several other test which need to conduct first like sieve analysis, compaction test, permeability test. We use the result of these test for preparing sample for NEF Test and start the test. Several test conducted on all different types of soil and their trend of result also analyzed. We can use this regression equation for knowing the result of some experiment without doing the real experiment. Which can save the real time and help to get the accurate results.

4.1 Sieve Analysis

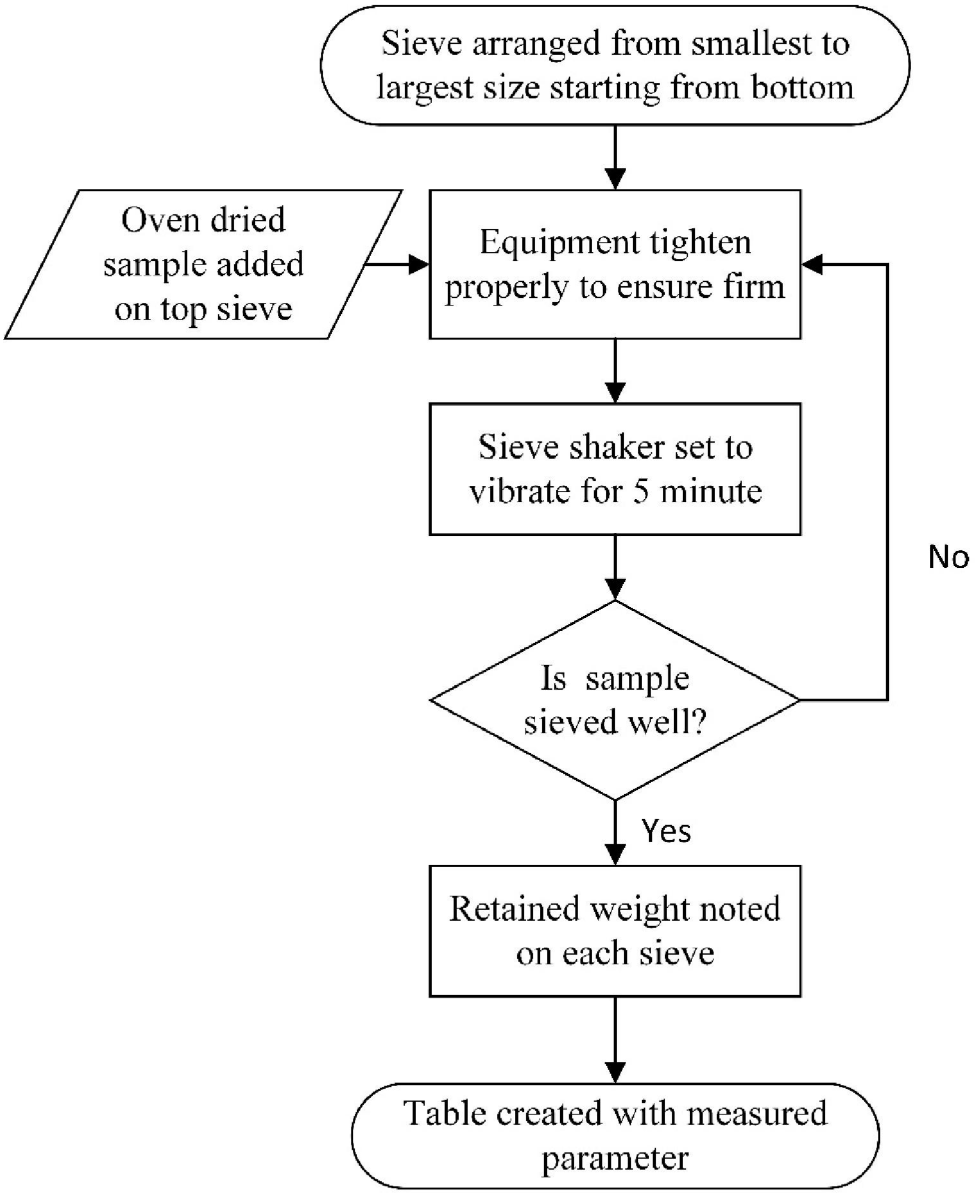
Sieve analysis is a technique used to determine the particle size distribution of a sample soil. This method is performed by sifting a soil sample through a stack of wire mesh sieves, separating it into discrete size ranges. A sieve shaker is used to vibrate the sieve for a specific period of time. Vibration allows irregularly shaped particles to reorient as they fall through the sieves.

It has great importance in many other experiments in soil like compaction test, permeability test and most important test i.e. No Erosion Filter Test (NEFT). For NEFT filter grain is also made with the help of sieve analysis by their respective grain size distribution obtained from the successful case of No erosion filter test.

4.1.1 Materials required

Sieve of different size or mesh no. 8,16,30,50,100,200 and 400, Weighing machine, and Sieve shaker assembly.

4.1.2 Procedure



4.1.3 Result

After proper sieve of the sample, mass of soil retained on each sieve is calculated then its cumulative percentage retained found out. Consecutively their percent finer also found by subtracting cumulative percentage retained by 100 percent. To found the properties of soil by their grain distribution a graph is drawn between percentage finer and their respective grain size. The properties of soil can be found out by look into the flow line the graph. If the flow line of graph is smooth, then it represents well graded sample while the line is not smooth then it represents poorly graded soil. The properties of soil can also be found out by knowing the percentage of soil passing from #200 sieve. If the percentage finer for #200 sieve is more than 85% then the soil belongs to clayey and when percentage finer is less, then soil is categorized as silty soil. For the below graph here shows the smooth flow which means the soil sample is well graded and percentage finer from #200 sieve is around 13% which shows the properties of sample as silty soil.

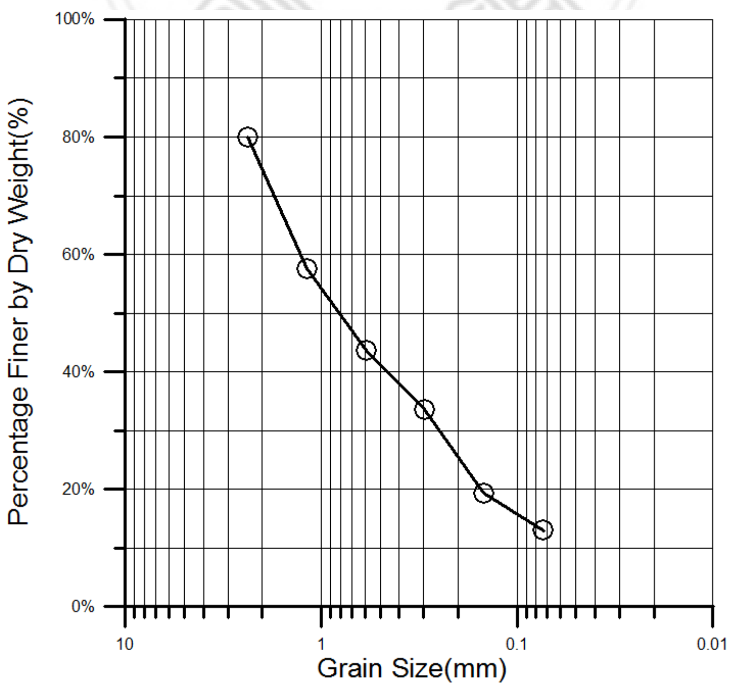


Figure 4-1: Sample graph for sieve analysis test

4.2 Permeability Test

The rate of flow of water, through a unit cross sectional area of soil mass, under unit hydraulic gradient, is defined as coefficient of permeability. Coefficient of permeability is used to understand drainage characteristics of soil, rate of consolidation of soil and for the prediction rate of settlement of soil bed. A number of factors affect the permeability of soils, from particle size, impurities in the water, void ratio, the degree of saturation, and adsorbed water, to entrapped air and organic material. The coefficient of permeability is generally determined by two procedures. One is constant head permeability method and other is falling head permeability method. The selection of method to determine coefficient of permeability of soil depends on the characteristics of soil and its physical structure. Soil having more course particle prefer constant head method while soil having fine particles a falling head method is preferred.

Permeability of the soil governs the magnitude of excess pore water pressure built-up in the embankment or cuttings, during consolidation process or when the embankment is ponded by water. The excess pore water pressure in turn significantly influences the stability of the embankments.

The coefficient of permeability (k) for constant head method is obtained from the relation

$$k = \frac{qL}{Ah} = \frac{Ql}{Aht} \qquad \ldots.. \ (1)$$

The coefficient of permeability (k) for falling head method is obtained from the relation

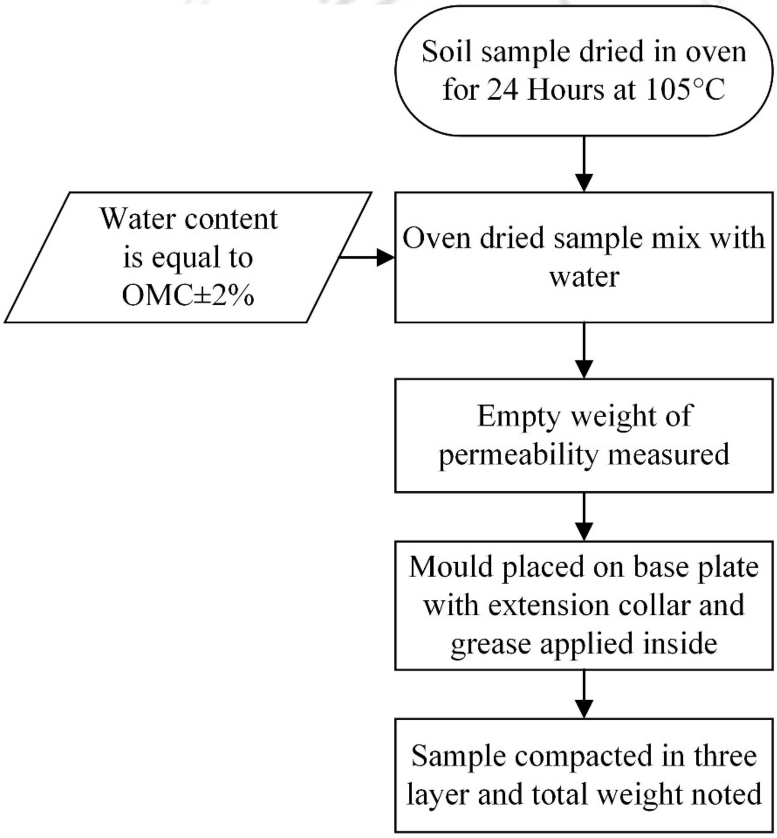
$$k = \frac{aL}{A\Delta t} \, ln\frac{h1}{h2} \qquad \ldots \ (2)$$

Where q = discharge in cm^3/sec, Q = total volume of water in cm^3, t = time period, h = head causing flow in cm, L = length of specimen in cm, A = cross-sectional area in cm^2, a = cross sectional area of burette, h_1= Hydraulic head across sample at beginning of test, h_2 = Hydraulic head across sample at end of test.

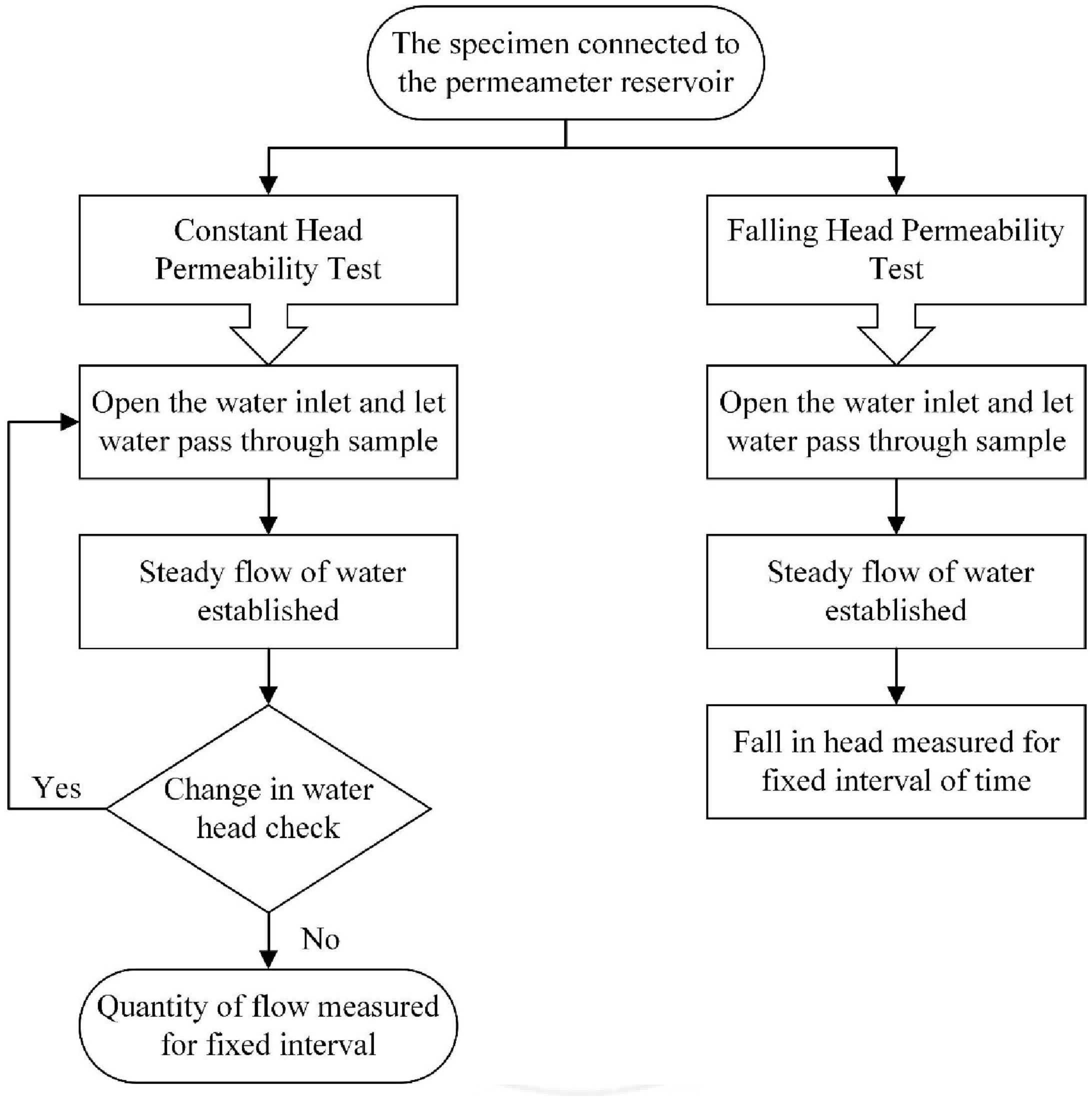
4.2.1 Materials required

Permeameter with its accessories, compacting equipment (A vibrating Tamper or a Sliding tamper with a tamping foot of 50 mm in diameter), Drainage base having porous disc, stop watch, weighing balance accuracy 0.1g, Filter paper, a meter scale to measure the head differences and length of specimen.

4.2.2 Preparation of specimen for testing



4.2.3 Test Procedure



4.2.4 Result

During test volume change and compressible air present in the voids of soil should be avoided i.e. soil should be completely saturated. And the flow should be laminar and in a steady state condition. Here, Area of cylinder 'a' (cm^2) = 0.442 cm^2; Cross Sectional Area of Sample 'A' (cm^2) = 80.873 cm^2; Length of sample 'L' (cm) =17 cm

Table 3. Sample table for Permeability Test

h1	h2	h1/h2	t(sec)
900	800	1.125	300
800	712	1.123595506	300
712	633	1.124802528	300
633	554	1.142599278	360
554	490	1.130612245	360
481	449	1.071269488	360
449	437	1.027459954	360
437	427	1.023419204	600

The average value of the coefficient of permeability for this sample was found to be, k= 2.54* 10^{-5} cm/sec by equation (1)

4.3 Compaction Test

The Proctor Compaction test is a laboratory method of experimentally determining the OMC at which a given soil type will become densest and achieve its maximum dry density. In this study, compaction test can be used to simulate the pressure condition of base soil under the ground. i.e. Compaction test can determine the relationship between soil moisture and unit weight of dry soil (γd), and thus determine the maximum dry density and OMC of base soil for the no erosion filter test.

4.3.1 Material required

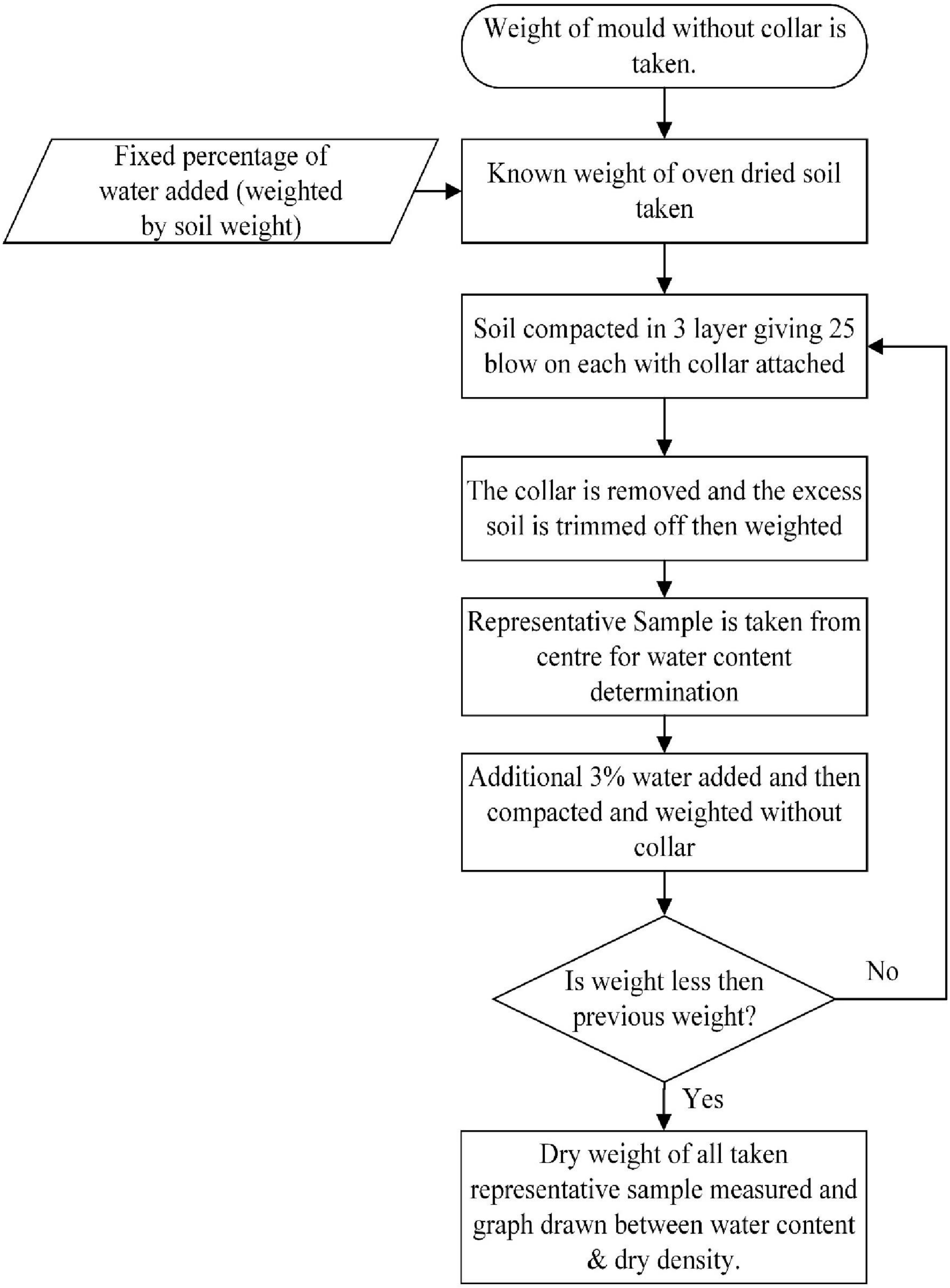
Sieve shaker, weighing machine, empty mould with inner diameter of 10.15cm, inner height of 11.7cm and volume of 946.21 cm together with the base plate, Rammer, Oven and Other equipment in determining the soil moisture content.

Figure 4-2 : Compaction Mould

Figure 4-3 : Rammer

Figure 4-4: Mixing Tray

4.3.2 Procedure



4.3.3 Result

The result obtained from compaction test gives the Optimum Moisture Content(OMC) and Maximum Dry Density(MDD) of any soil. This result is very useful to do other experiment related to soil properties or characteristics. The coordinate of the peak of the curve gives the value of OMC and MDD. The equation of the curve can also be found which satisfy the given condition. Differentiating the equation of the curve can also provide the peak value.

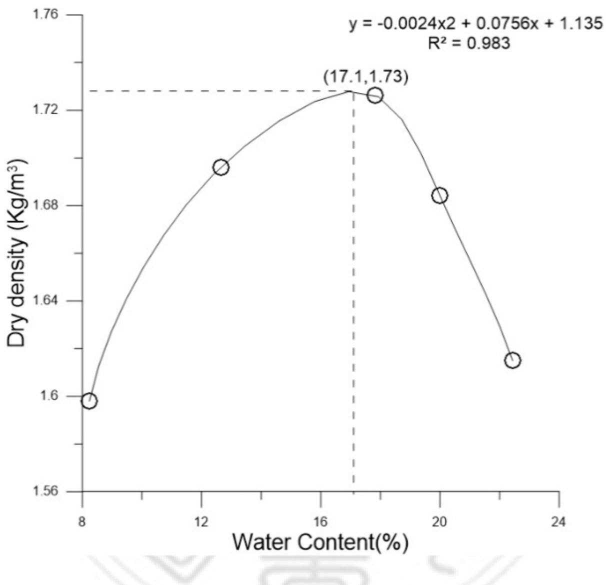


Figure 4-5: Sample graph for compaction

4.4 No Erosion Filter Test

The NEF test is the best available test for evaluating critical filters located downstream of impervious cores under the soils. This is considered the most valuable single conclusion from the four-year long research effort by Sherard (1989). The conditions in the simulation of the most severe conditions that can develop inside the earth from a concentrated erosive leak through the core discharging into a filter. This test helps to find out the filter grain distribution which is suitable for the given soil.

4.4.1 Material required

A. Equipment Preparation

Acrylic Cylindrical Container consists of two dimension. The Upper part with 10cm x 10.2cm dimension and the Lower part with 10cm x 17.8cm dimension. In installing, the lower cylinder is fixed first by bolting four length-adjustable brackets on the bottom plate. Then, the Upper cylinder is adapted to the Lower one by linking individually the four stainless bars with four brackets. The full dimension of the container becomes 10cm x 28cm. Finally, a cap plate, the same size as the bottom plate with the dimension of 14.5cm x 14.5cm x 2.5cm is covered on the upper cylinder. Two holes are drilled on the plates to intake water, drain water and exhaust air away from the container. The container must be examined to ensure that there is no leaking and cracking prior to work using a high water pressure (6kg/cm^2) for 24 hours.

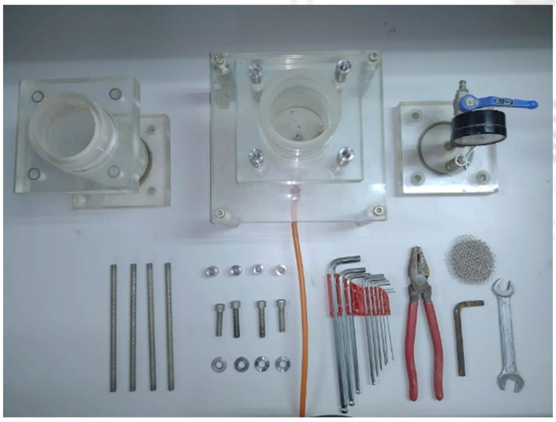


Figure 4-6: Cylindrical container equipment components

Figure 4-7 : Cylindrical component

Figure 4-8: #4~3/8 inch gravels

Pressure Control System contains a Stainless Water Tank with the dimension of 30cm x 140cm supplies water for the piping and the filter tests and can provide water up to 100 liters. An air pressure gauge and pressure adjustment valve are then setup to adjust and transport pressure. The tank is then connected with the acrylic cylindrical container using high pressure plastic pipes and water pressure meter is also installed to measure the water pressure.

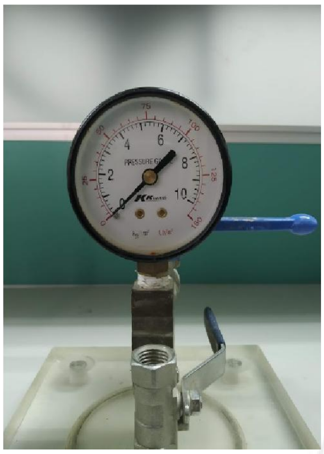


Figure 4-9: Air pressure gauge

Figure 4-10: Pressure adjustment valve

Figure 4-11: Water tank

B. Specimen Design

1. The wire mesh is laid at the bottom of the cylindrical container and heap #4~3/8 inch gravels about 6cm heights on the mesh as the filter layer. Then, another layer of wire mesh was laid to separate the layer and the filter grains.

2. The filter grains was compacted into the container by 14 times of compaction in constant volume. Herein, the water content of filter grains satisfies the standard Proctor test with O.M.C±2%; The thickness of compaction is 5.5cm; then, water is added into the sample until saturation.

3. The model clay is rubbed as stripes and attached on the wall of container at 14.5~17.5cm height to avoid the flow on the wall.

4. Step 2 is repeated to compact more filter grains until 3cm thickness of

compaction.

5. Then, filter grains is compacted again into the container by 10 times of compaction in constant volume. Herein, the water content of filter grains satisfies the standard Proctor test with O.M.C±2%; The thickness of compaction is 5.5cm; then, add water into the sample till saturation.

6. A 1.0 mm preformed hole is done in base for fine soil and 5 mm to 10 mm for coarse soil.

6. Heap #4~3/8 inch gravels about 10 cm heights for disturbing flows to yield static water pressure.

7. Finally, complete the specimen and add water into the pores among the gravels that lay above the base soils until the water overflows from the exhaust hole.

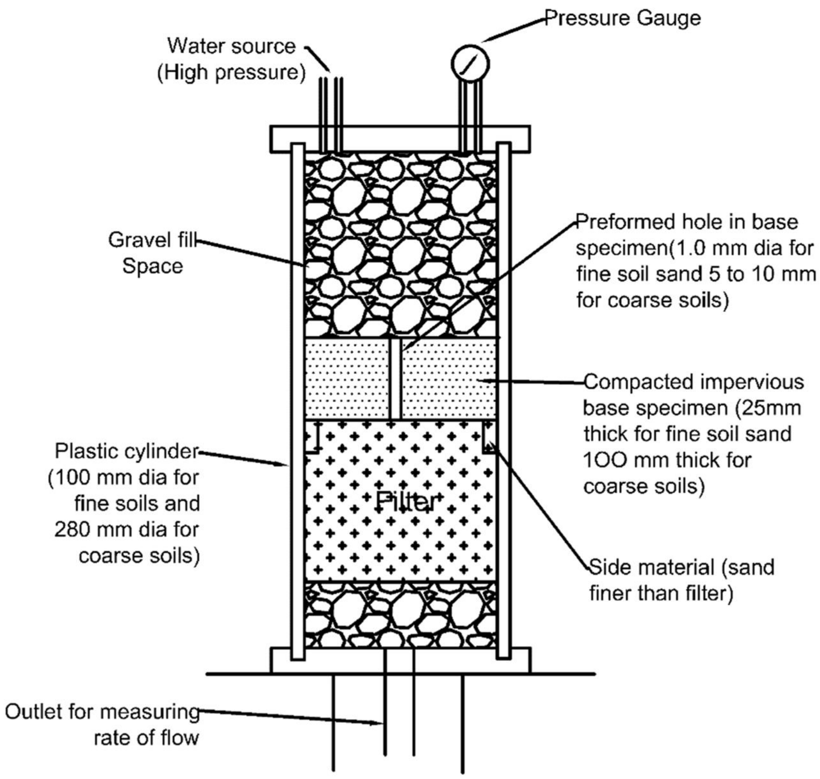
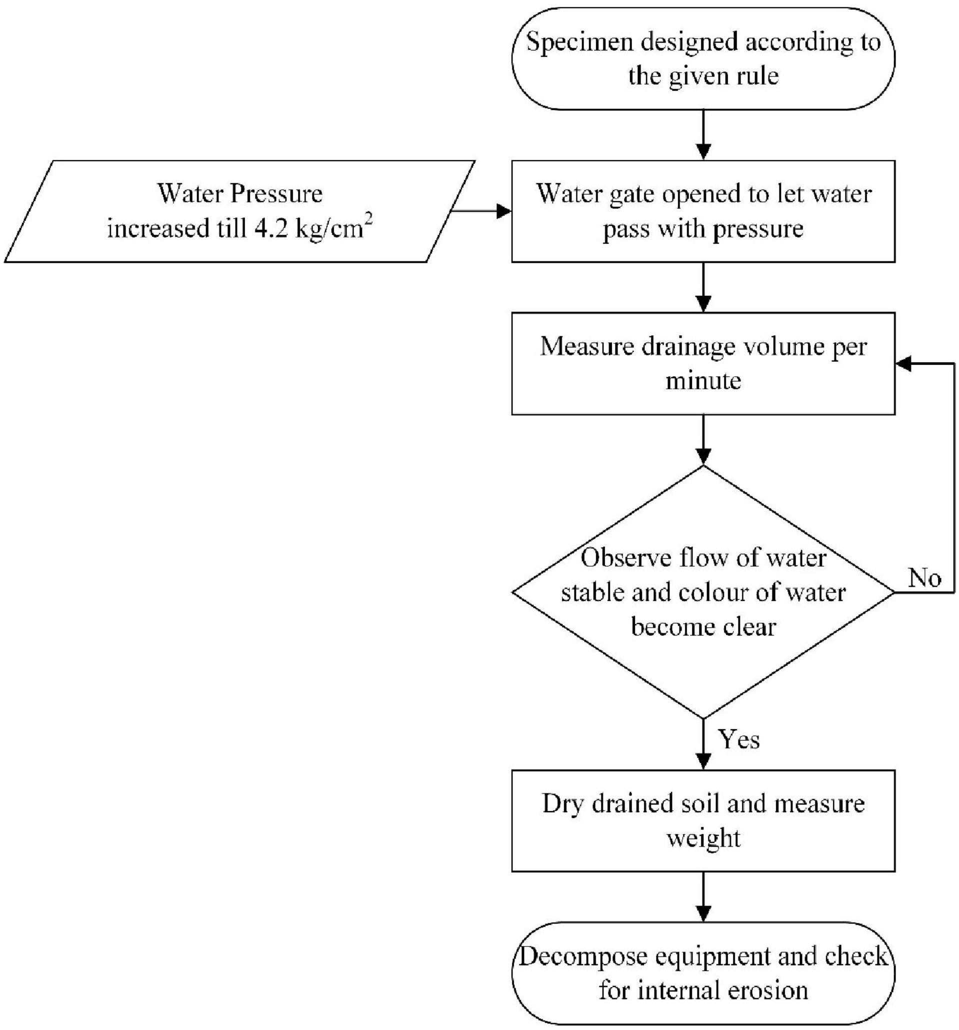


Figure 4-12: Layout diagram of NEFT cylinder container

4.4.2 Procedure



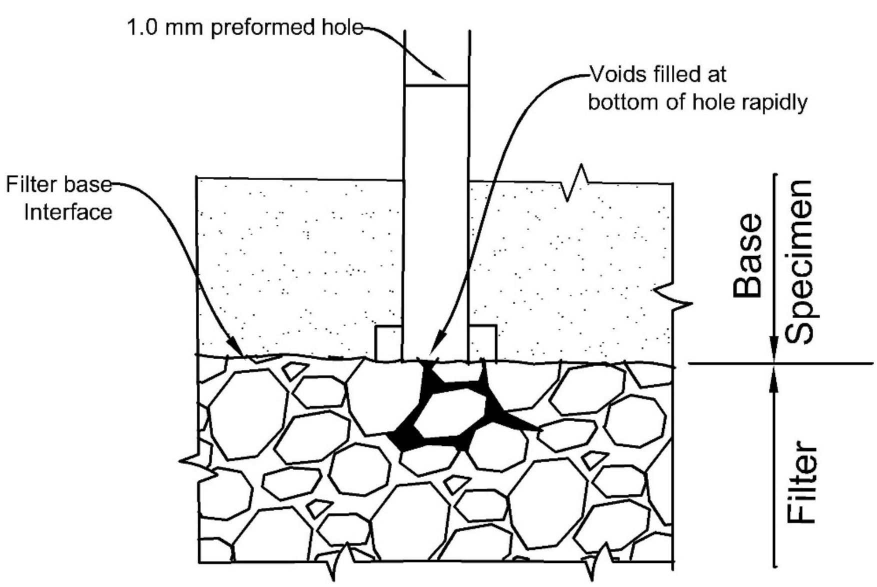


Figure 4-13: Layout diagram of after NEFT Test

Table 4. Different trial chosen for NEF Test

Soil type (By % Passing from #200 sieve)	d_{15}	d_{85}	Minimum D_{15}	Maximum D_{15}	Trial_1	Trial_2	Trial_3	Trail_4	Trail_5
10%	0.084	2.016	0.336	8.064	0.336	2.268	~~4.2~~	~~6.132~~	~~8.064~~
20%	0.049	2.527	0.196	10.108	0.196	2.674	~~5.152~~	~~7.63~~	~~10.108~~
30%	0.035	2.687	0.14	10.748	0.14	2.792	~~5.444~~	~~8.096~~	~~10.748~~
50%	0.022	1.864	0.088	7.456	0.088	1.93	3.772	~~5.614~~	~~7.456~~
70%	0.016	0.59	0.064	2.36	0.064	0.638	1.212	1.786	~~2.36~~
90%	0.012	0.07	0.048	0.28	0.048	0.106	0.164	0.222	0.28

Here five different value of D_{15} have been chosen between its minimum and maximum range for every soil types. The five different value is named as the five different trial. Each trial is used to make the filter sample and to check the success against NEFT. There are some trials which are strikethrough here, which means that test is not feasible to do it in laboratory with the present equipment because of the larger grain size.

4.4.3 Result

Figure 4-14: Successful NEF Test

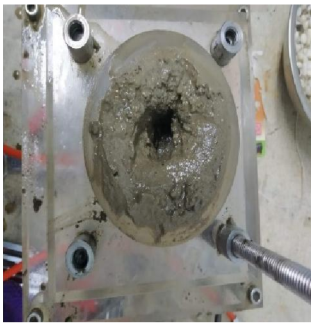


Figure 4-15: Unsuccessful NEF Test

The successful and unsuccessful NEFT can be easily found out by looking into the bottom of the base sample. If the preformed hole gets bigger in size from the initial size it means that the base soil gets eroded and get into the gravel which means it is an unsuccessful case. While in successful NEFT case the initial hole in base soil remains same like earlier. Very few amount of soil pass through the water while passes through the base. The criteria for successful and unsuccessful can also be determined by amount of drainage of soil during the experiment. The drainage of soil can be collected per minutes or certain fixed interval of time. And their dry mass calculated then that data can be analyzed to understand the successful or unsuccessful of test. If there are large mass of soil pass though the water which shows the base soil get eroded by the applied pressure and it is not the successful case. So new grain size distribution for filter need to be tested until the successful case comes.

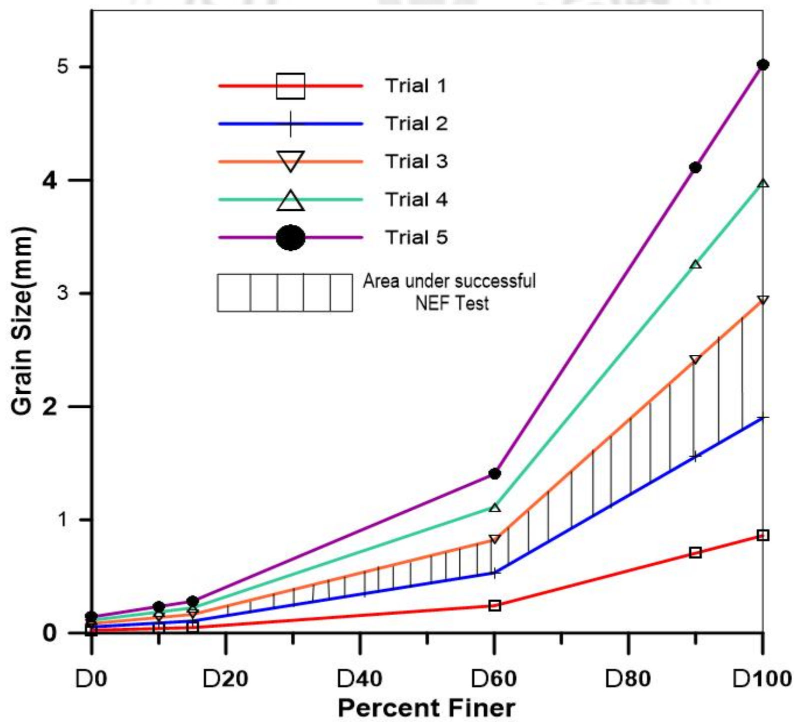


Figure 4-16: Result of NEFT for 90% passing #200 sieve soil

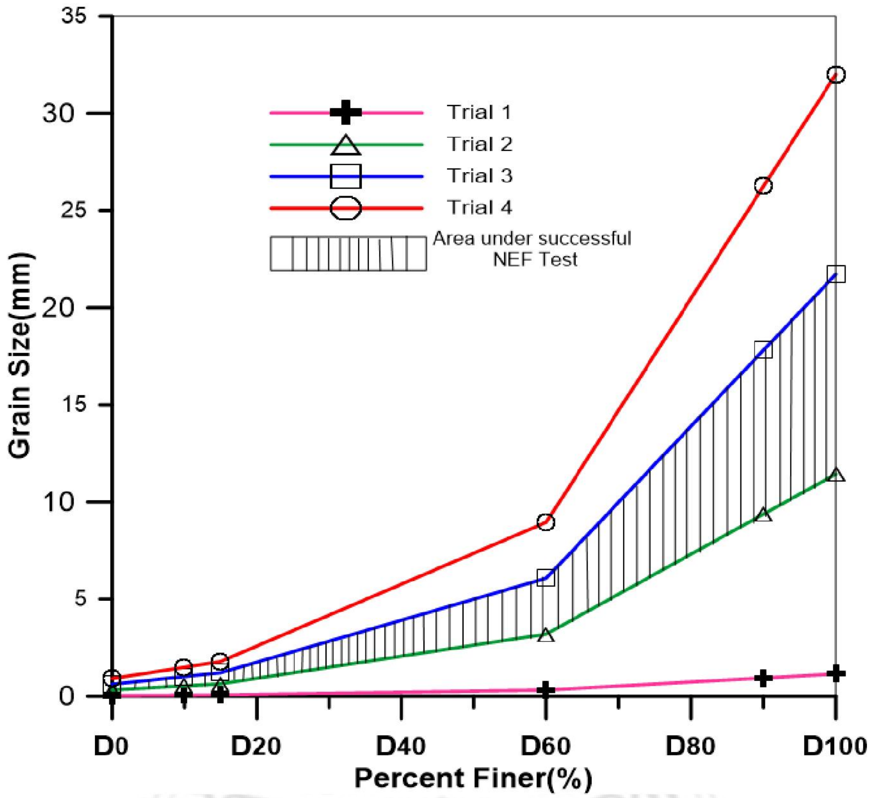


Figure 4-17: Result of NEFT for 70% passing #200 sieve soil

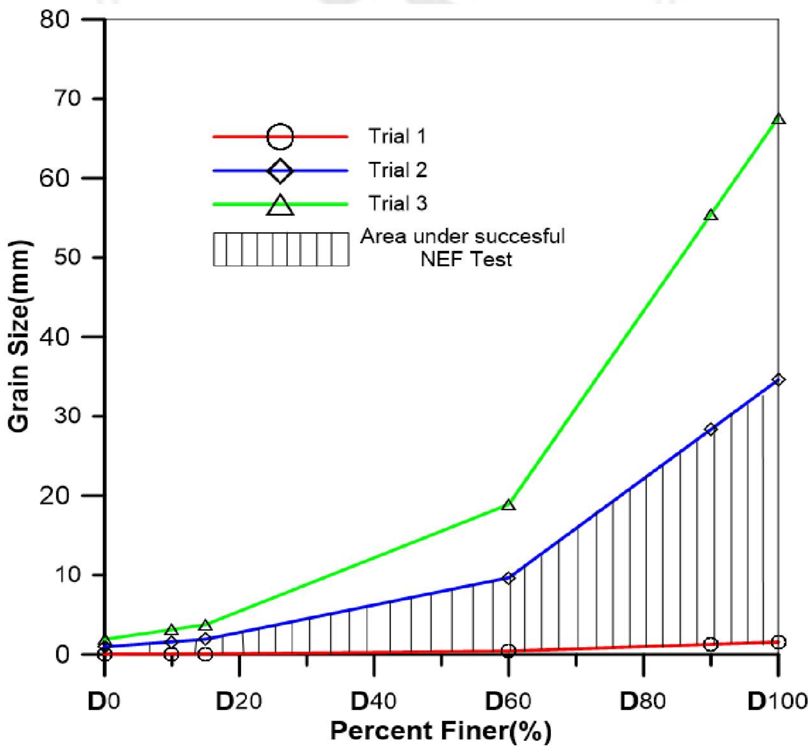


Figure 4-18: Result of NEFT for 50% passing #200 sieve soil

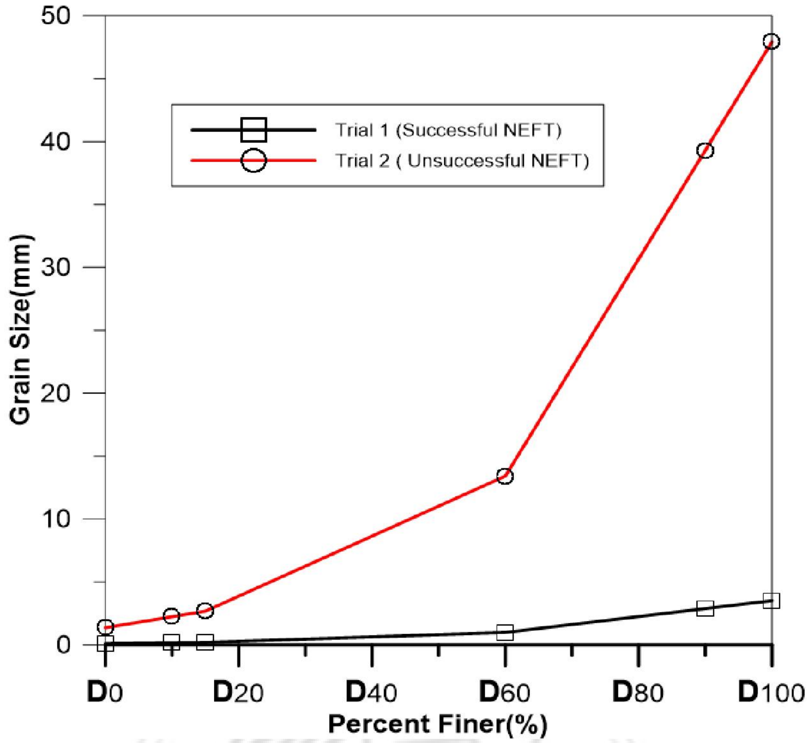


Figure 4-19: Result of NEFT for 30% passing #200 sieve soil

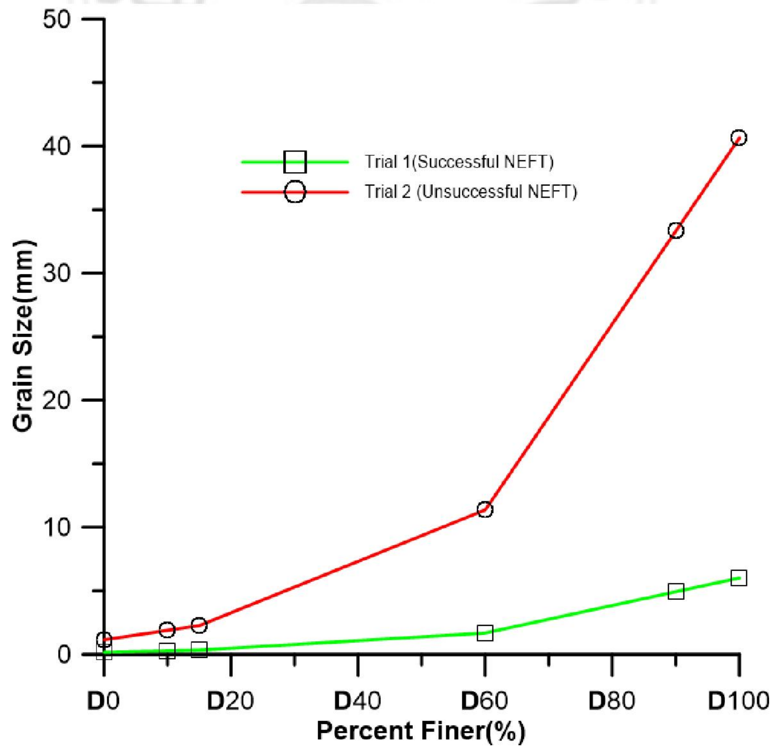


Figure 4-20: Result of NEFT for 20% passing #200 sieve soil

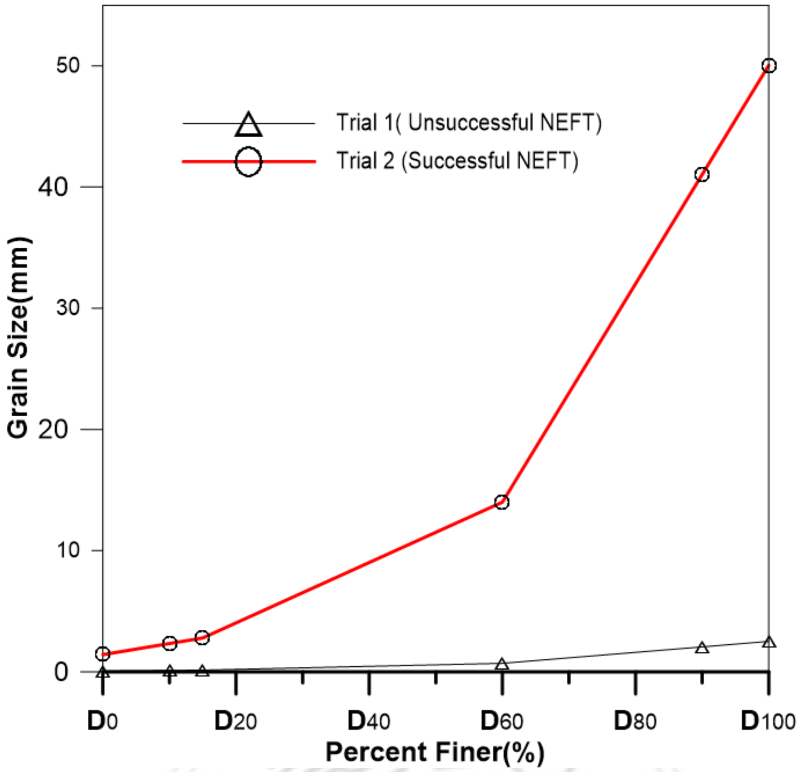


Figure 4-21: Result of NEFT for 10% passing #200 sieve soil

Chapter 5 – Discussion

5.1 Sieve analysis

This test is very important to distinguish the soil into its different types. It also helps to make the filter sample according to its percentage Finer value got from the formulas. The entire range of soil can be classified into 4 different group of soil.

(a)Soil group 1— Fine silts and clays with more than 85% passing the No. 200 sieve.

(b)Soil group 2 — Silty and clayey sands and sandy silts and clays with 40-85% passing the No.200 sieve.

(c)Soil group 3 — Soils intermediate between groups 2 and 4

(d)Soil group 4 — Silty sand and gravelly sands with 15% or less Passing the No.200 sieve.

5.2 Permeability test

Initially the flow from the outlet is not constant so it need to wait until the laminar flow obtained to take record for the experiment data. And from the experimental data it can be easily concluded that with increase in the percentage passing from #200 no. sieve permeability of soil decrease which means that coarser soil has more permeability while clay soil has less permeability.

This experiment is also done with 3 different sample for every six different percentage of soil passing #200 no. sieve. The average value of permeability is also calculated and plotted in graph.

The regression relationship for the given graph is $k = 0.324e^{-0.121\ Pr}$

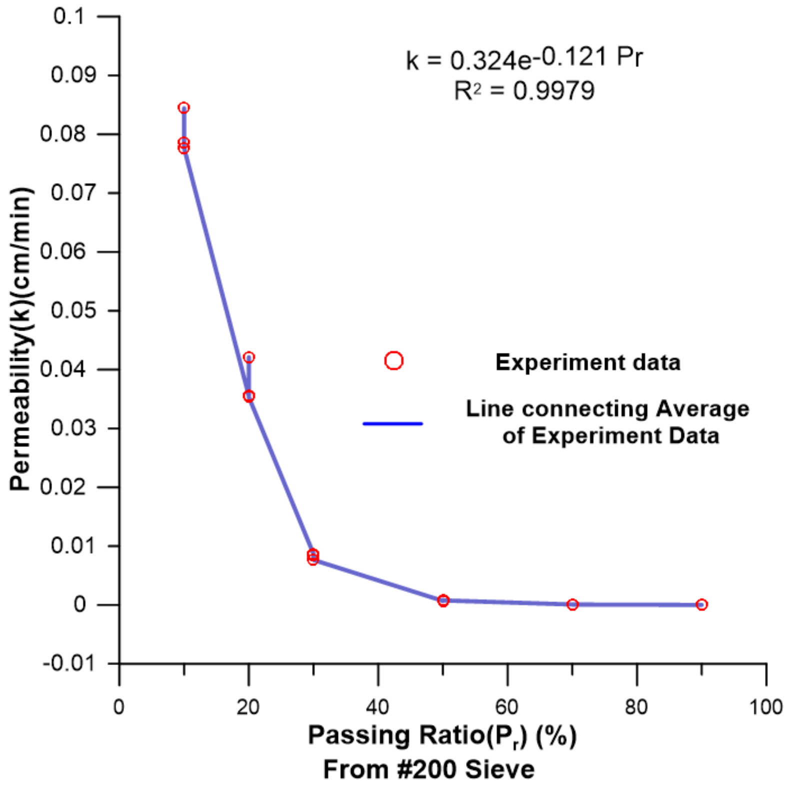


Figure 5-1 : Graph for different soil sample and their Permeability

5.3Compaction test

The graph shown gives the relation between different passing ratio of soil and their related OMC. Three different sample for each 6 types of soil sample with percentage of 10%, 20%, 30%, 50%, 70% and 90% of soil passing through the #200 sieve have been shown here with their OMC value. The regressive relationship for the given graph is O.M.C = - 0.0004 P_r^2 + 0.0768 P_r + 14.132

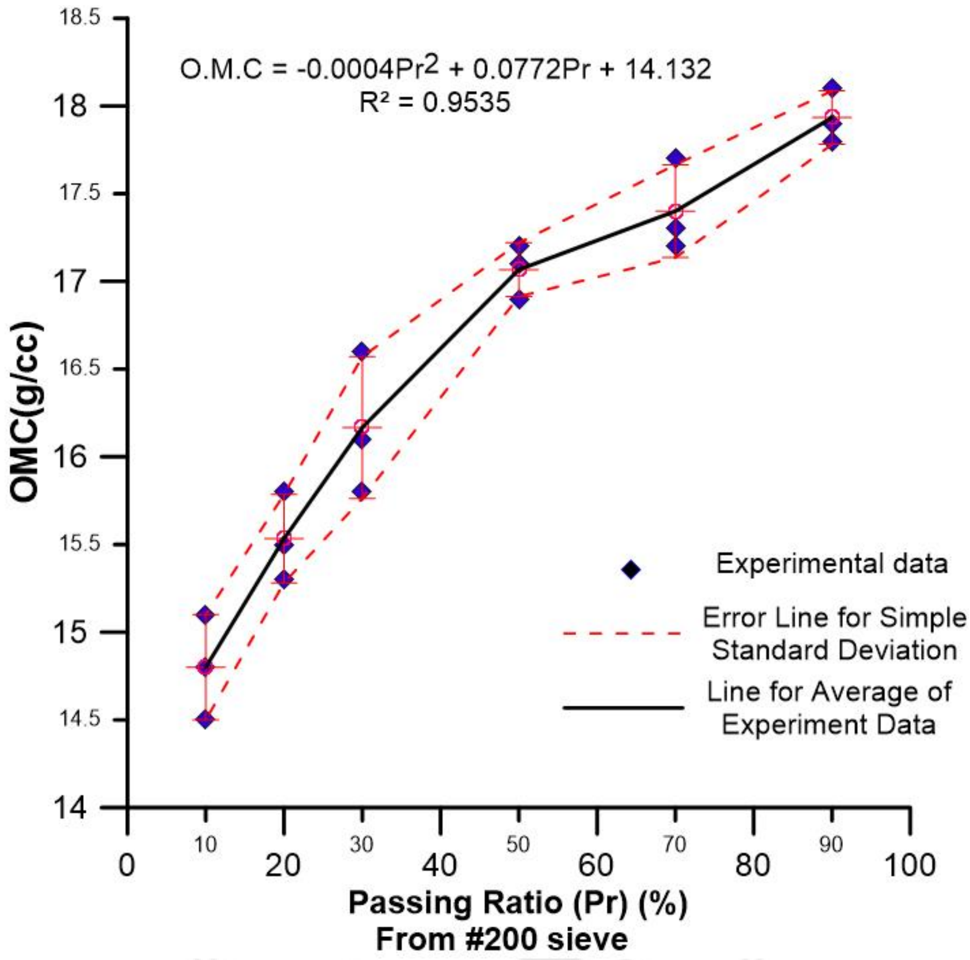


Figure 5-2: Graph for different soil sample and their OMC

The line for average of experimental data shows the trends of increasing in OMC with increase in soil passing ratio through #200 sieve. And their error line for simple standard deviation is also not too much deviate from average line. The increase in O,M.C is due to increase in the number of grains. More grain means more surface area so it need more water to achieve maximum dry density.

5.4 No Erosion Filter Test

The successful rate of Test against NEFT for different Trial in each types of soils shown in graph. It can be concluded through that in almost every cases the middle range of D_{15} from their minimum and maximum value are giving successful result. But for 90% to 50% passing soil from #200 sieve have more number of trial done so for their range of successful rate can be find from the graph shown below. From this graph the value of D_{15} can be found for successful filter design easily for soil types having 90% to 50% passing ratio from #200 sieve.

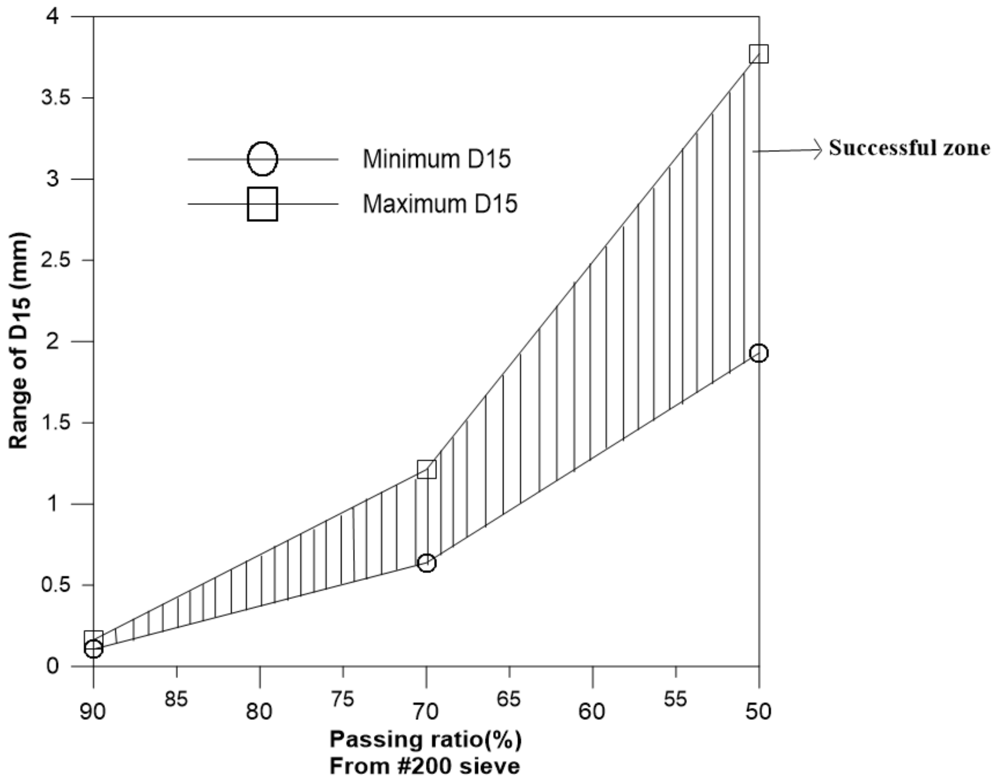


Figure 5-3: Graph for different passing ratio of soil sample and their range of D_{15}

Chapter 6 - Conclusions

In this study three different soil test have been done for various soil for example soil having 10%, 20%, 30%, 50%, 70% and 90% of soil passing through the #200 sieve. These soil have been categorized into four basic soil group. According to their percentage of silt and clay in soil. Further their compaction test done to find their OMC and MDD. These value can be further use in the next test like permeability test or NEFT. Average trend line for all type of soil to get their OMC also drawn. Permeability of all different types of soil also found out and their basic trends plotted into graph. Next test is NEF Test. This test done to find out the perfect filter grain size distribution for Ground water monitoring well. This research adopted the equation from the past researches and try to modify the equation and give some better result. It successfully reduced the range of D_{15} and for soil having passing ratio from 90% to 50% from #200 sieve range of D_{15} can be found easily from graph shown.

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Appendix

Appendix I : Data of sieve analysis

(a) For 10% soil passing from #200 sieve

Sieve no.	Sieve size(mm)	Mass of Soil retained(g)	Percentage retained on each soil(%)	Cumulative percentage retained(%)	Percent finer(%)
8	2.38	124	12.40	12.4	87.6
16	1.19	85	8.50	20.9	79.1
30	0.59	90.5	9.05	30.0	70.1
50	0.297	119.5	11.95	41.9	58.1
100	0.149	290	29.00	70.9	29.1
200	0.074	162	16.20	87.1	12.9
Receiving pan	0	129	12.90	100.0	0.0

(b) For 20% soil passing from #200 sieve

Sieve no.	Sieve size(mm)	Mass of Soil retained(g)	Percentage retained on each soil(%)	Cumulative percentage retained(%)	Percent finer(%)
8	2.38	178	15.99	16.0	84.0
16	1.19	128.5	11.55	27.5	72.5
30	0.59	89	8.00	35.5	64.5
50	0.297	155.5	13.97	49.5	50.5
100	0.149	168	15.09	64.6	35.4
200	0.074	142	12.76	77.4	22.6
Receiving pan	0	252	22.64	100.0	0.0

(c) For 30% soil passing from #200 sieve

Sieve no.	Sieve size(mm)	Mass of Soil retained(g)	Percentage retained on each soil(%)	Cumulative percentage retained(%)	Percent finer(%)
8	2.38	172.5	17.23	17.2	82.8
16	1.19	95	9.49	26.7	73.3
30	0.59	187	18.68	45.4	54.6
50	0.297	75	7.49	52.9	47.1
100	0.149	62.5	6.24	59.1	40.9
200	0.074	87	8.69	67.8	32.2
Receiving pan	0	322	32.17	100.0	0.0

(d) For 50% soil passing from #200 sieve

Sieve no.	Sieve size(mm)	Mass of Soil retained(g)	Percentage retained on each soil(%)	Cumulative percentage retained(%)	Percent finer(%)
8	2.38	175	12.34	12.3	87.7
16	1.19	87	6.14	18.5	81.5
30	0.59	118	8.32	26.8	73.2
50	0.297	62	4.37	31.2	68.8
100	0.149	176	12.41	43.6	56.4
200	0.074	87.5	6.17	49.8	50.2
Receiving pan	0	712.5	50.25	100.0	0.0

(e) For 70% soil passing from #200 sieve

Sieve no.	Sieve size(mm)	Mass of Soil retained(g)	Percentage retained on each soil(%)	Cumulative percentage retained(%)	Percent finer(%)
8	2.38	53	4.10	4.1	95.9
16	1.19	94	7.27	11.4	88.6
30	0.59	47	3.63	15.0	85.0
50	0.297	102.5	7.93	22.9	77.1
100	0.149	47.5	3.67	26.6	73.4
200	0.074	25	1.93	28.5	71.5
Receiving pan	0	924	71.46	100.0	0.0

(f) For 90% soil passing from #200 sieve

Sieve no.	Sieve size(mm)	Mass of Soil retained(g)	Percentage retained on each soil(%)	Cumulative percentage retained(%)	Percent finer(%)
8	2.38	7.5	1.50	1.5	98.5
16	1.19	6	1.20	2.7	97.3
30	0.59	4	0.80	3.5	96.5
50	0.297	3.5	0.70	4.2	95.8
100	0.149	7.5	1.50	5.7	94.3
200	0.074	21.5	4.30	10.0	90.0
Receiving pan	0	450	90.00	100.0	0.0