ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

APPROPRIATE SOLUTION FOR IMPEVIOUS CORE OF EMBANKMENT DAMS TO BE CONSTRUCTED USING HIGHLY PLASTIC SOILS

(The Case of Tendaho Dam)

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF
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BY

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November 2007

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Table of Contents **Page**

Notations

ASTM - American society for testing materials

Cc - Compression index

CH - Inorganic clays of high plasticity

CL - Inorganic cays of low to medium plasticity

Cu - Uniformity coefficient

D10 - Size of materials for which 10% by weight is finer

D15F - Size of 15% of the filter material is finer

D15B - size of 15% of the Base (protected) material is finer

D30 - Size of materials for which 30% by weight is finer

D60 - Size of materials for which 60% by weight is finer

GC - Clayey gravels, Gravel-Sand-Clay mixtures

Gs - Specific gravity

GW - Well-graded gravels, gravely- sand mixtures, little or no fines

Ip, PI - Plasticity index

LL, WL - Liquid limit

MDD, gdmax - Maximum dry density

OMC, wopt - Optimum moisture content

SC - Clayey sands, Sand-Clay mixtures

SP - Poorly-graded sands, gravely sands, little or no fines

SW - Well-graded sands, gravely sands, little or no fines

U.S.B.R - United States Department of the Interior Bureau of Reclamation

USCS - Unified soil classification system

UU - Undrained unconsolidated

WWDSE - Water works Design and Supervision enterprise.

1D - One dimensional

List of Figures

List of tables

List of Appendices

ABSTRACT

For a long time, highly plastic clays (CH soils) have been used extensively as impervious core material for many zoned embankment dams all over the world. In Ethiopia several dams are currently under construction (e.g. Tendaho dam) and more are planned to be constructed (e.g. Ribb, Megech, Meqa dams, etc.) using predominantly CH soils as the most available impervious core material.

Nevertheless, several problems are associated with CH soils. The most common problems include high compressibility when saturated, potential for high swelling and cracking, slow rate of construction for safe dissipation of pore water pressure, large difference in stiffness with the surrounding shell materials leading to differential deformation, difficulty in moisture control during construction, and requiring extremely fine filters that can not be easily obtained or produced on site.

In this thesis, a study has been conducted on the effects of blending the CH soils with naturally available granular materials using several laboratory tests. The laboratory tests include Atterberg limits, permeability, compaction, 1D-consolidation, and triaxial compression tests on samples collected from Tendaho dam site. The test results clearly reveal that blending with granular soils greatly improves the physical and mechanical behaviours of the CH soils. Based on the test results, an appropriate blending ratio has been recommended for the CH soils used in Tendaho dam.

1 INTRODUCTION

1.1 General

The core of an embankment dam plays an important role in seepage control and stability of dams. Although different types of materials such as asphalt, bituminous, and concrete are used as impervious core in embankment dams, clayey soils are widely used because they are very economical and the differences between the nature of the earth dam main material (shell) and the asphalt or concrete core materials usually causes a significant contrast in deformation behavior, leading to differential settlement.

Highly plastic clays (CH soils) have also been used extensively as impervious core material for many zoned embankment dams. However, the following problems are encountered when CH soils are used as impervious core.

- The compaction procedure for filling the core is relatively long.
- The pore pressure build up in the core during construction is relatively fast but its dissipation is very slow.
- The disparity in stiffness of the fine cohesive core materials (CH soil) and coarse granular shell materials are high and the differential settlement between these two zones may cause major problems.
- CH soils usually require extremely fine filters that can not be easily obtained or produced on site.

It is therefore appropriate to consider some remedial measures or construction techniques to avoid any failure from such properties of the soils there by augmenting the advantages of the soils. In order to tackle the above problems, the use of clays mixed with sand and/or gravel can be one of the appropriate techniques. The type and size of the granular materials to be added, the percentage of the mixture, and the practical and theoretical considerations for these mixed materials are among the main issues that need to be discussed and clarified. In this thesis, a study has been conducted on the effects of blending the CH soils with naturally available granular materials using several laboratory tests. The case of Tendaho dam has been considered in this study and the necessary soil samples have been collected from the dam site. The materials produced by mixing CH soils with coarse granular materials are referred to as "mixed clay" in this thesis.

1.2 Background of the Problem

One of the most important problems facing the world is the provision of adequate supplies of water for industry, for agriculture and for the very continuance of mankind. These factors and others highlight the importance of water and the need to apply maximum engineering skills to its conservation, and it has forced engineers in to the art of dam engineering.

In different parts of Ethiopia, there are several dam projects under construction and planned to be constructed, including Tendaho and Kesem dams (Afar), Koga, Ribb, Megech dams (Lake Tana sub-basin), Maqa dam (Nekemt), etc.

The geotechnical study reports obtained from most of the above dam projects state that the materials obtained for the core of the dam are predominantly inorganic highly plastic (CH) soils [3,16,17, &18]. However, highly plastic soils have a property of high compressibility when saturated, poor shear strength when compacted and saturated, potential for high swelling and cracking, difficulty in moisture control during construction (poor workability), slow rate of construction so that pore pressure is dissipated safely, and causing some difficulties and time consuming procedure to provide fine filters particularly for large volumes. According to Wagner [10], CH soils are the least preferred soils for impervious core of a dam. It is therefore understandable that constructions with these types of soils are often avoided when ever possible.

However, these soils are found in many parts of the country and sometimes there are no other better and more economical alternatives. As a result, the utilization of these marginal soils is required in increasing number of instances in recent years. Therefore, suitable geotechnical design and construction technique need to be found for this type of construction materials.

1.3 Objective

The objective of this study is to examine and improve the undesirable properties of highly plastic soils like Atterberg limits, compaction characteristics, and swelling characteristics, and to improve gradation & filter criteria requirements, so as to make it usable construction material of best quality.

The improved material to be used in the clay core of earthen dams is expected to do all duties expected for the core of the earth dams in a more suitable way than the highly plastic clay cores.

1.4 Methodology

To achieve the objectives of this thesis, the following methodologies have been followed.

- Literature review.
- Gathering necessary data from Water Works Design and Supervision Enterprise and Tendaho dam & irrigation project.
- Sample collections from different borrow areas in Tendaho dam site.
- Conducting a series of laboratory tests, including:
    - Grain size analysis (sieve, hydrometer).
    - Specific gravity.
    - Atterberg limits (liquid limit, plastic limit).
    - Swelling characteristic (free swell).
    - Permeability.
    - Compaction (MDD, OMC).
    - 1D Consolidation.
    - Triaxial Compression (UU).
- The above tests were conducted for both naturally available highly plastic clay, and mixed clay under different blending ratio (10% to 50% by volume).

2 Literature review

2.1 Embankment Construction Materials

2.1.1 General

The design of earth and rock-fill dams involves many considerations that must be examined before initiating detailed design analyses. Following subsurface and geological explorations, the earth and/ or rock-fill materials available for construction should be carefully studied. The study should include the determinations of the quantities of various types of material that will be available and the sequence in which they become available, and a thorough understanding of their physical properties is necessary. Failure to make this study may result in erroneous assumptions, which must be revised at a later date.

The quantities and properties of the materials from the required excavations for the structure often have an important influence on the embankment design. Theoretically earth dam embankments can be designed in such a way that soils of any type can be used. Practically large organic soils (peat) are not chosen because of low shear strength and high compressibility. Because of the construction difficulties inorganic clays of high plasticity (CH soils) are not desirable except when no other materials are available.

2.1.2 General requirements for core materials

a) While most clayey soils can be used for impervious core construction as long as they are insoluble and substantially inorganic, typically clays with liquid limits above 80 should be generally avoided [11].

b) If a fine-grained soil can be brought readily with in the range of water contents suitable for compaction and for the operation of the equipment, it can be used for embankment construction. Some slow drying impervious soils may be unusable as embankment fill because of excessive moisture, and the reduction of moisture content would be impracticable in some climatic areas because of anticipated rainfall during construction. In other cases, soils may require additional water to approach optimum water content for compaction. The use of fine-grained soils having high water contents may cause high pore water pressures to develop in the embankment under its own weight [11].

c) As it is generally difficult to reduce substantially the water content of impervious soils, borrow areas containing impervious soils wet of optimum water content (depending on their plasticity characteristics) may be difficult to use in an embankment [11].

d) Other factors being equal, and if a choice is possible, soils with a wide range of grain size (well graded) are preferable to soils having relatively uniform particle sizes, since the former are usually stronger, less susceptible to piping, erosion, and liquefaction, and less compressible. Cobles and boulders in soils may add to the cost of construction since stone with maximum dimensions greater than the thickness of the compacted layers must be removed to permit proper compaction. [14]

e) For the impervious materials to be used in the clay core of earthen dams, limits of maximum dry unit weight, optimum water content, specific gravity, liquid limit and plasticity index have been given as: g_{dmax}.>1.6g/cm3, w_{opt}=15-20%,Gs>2.6, LL=40-50% and Ip=14-20% [7 & 15].

2.2 Highly plastic clay (CH) soils

Soils containing large quantities of silt and clay are the most troublesome to the engineer. These materials exhibit marked changes in physical properties with change in water content. Many of the fine soils shrink on drying and expand on wetting, which may adversely affect structures founded upon them or constructed of them. Even when the water content does not change, the properties of fine soils may vary considerably between their natural conditions in the ground and their states after being disturbed. Deposits of fine particles that have been subjected to loading in geologic time frequently have a structure that gives the material unique properties in the undisturbed state. When the soil is excavated for use as a construction material or when the natural deposit is disturbed, the properties of the soil changes radically.

Generally, highly plastic clays (CH soils) have low resistance to deformation when wet, but they dry too hard due to cohesion. They are virtually impervious, difficult to compact when wet, and impossible to drain by ordinary means. Large expansion and contraction with changes in water content are characteristics of clays. The small size, flat shape, and mineral composition of clay particles combine to produce a material that is both compressible and plastic. Generally the higher the liquid limit of a clay, the more compressible it will be. Differences in the plasticity of clays are reflected by their plasticity indexes. At the same liquid limit, the higher the plasticity index, the more cohesive the clay is.

For highly plastic cohesive soils, pore pressures produced by compaction, increase rapidly with increase in moisture content in the vicinity of the peak of compaction curve. Compaction of the soil in the moisture content less than the optimum has relatively lower pore pressure.

The permeability of highly plastic fine grained clay soils are several orders of magnitude lower than that of coarser soils, i.e. sands and gravels. Permeability laboratory testing methods for the main soil types and their classifications on the basis of permeability are shown in Fig 2.1. It has been recognized that the finer particles in a soil largely determines its permeability [12, 14].

According to engineering use of chart developed by Wagner [10] and summarized in Table 2.1, CH soils are impervious, posses poor shear strength and high compressibility when compacted and saturated, and its workability is poor when used as embankment construction materials.

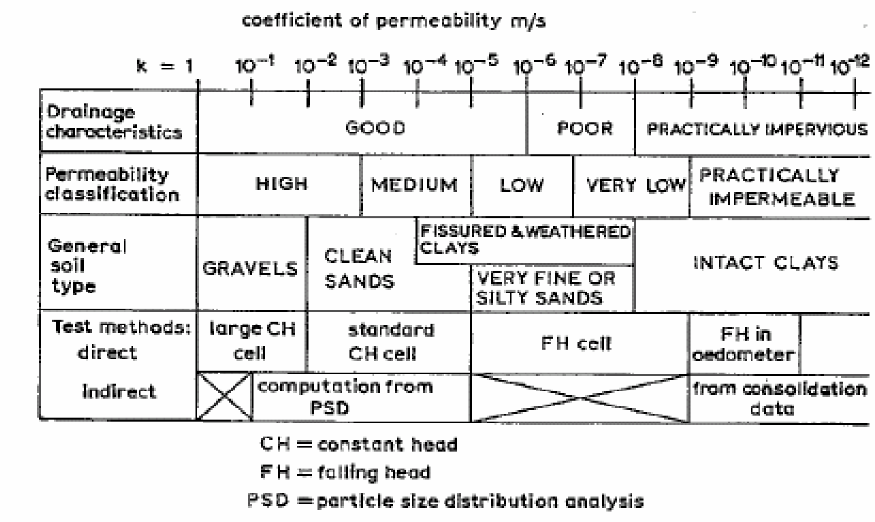


Figure 2.1: Permeability and laboratory testing methods for the main soil type (Head, 1985).

Table 2.1: Engineering Use Chart *(Wagner*, 1957)

Soil group symbols	Permeability when compacted	Shear strength when compacted and saturated	Compressibility when compacted and saturated	Workability as construction material	Relative Desirability as core material
GC	Impervious	Good to fair	Very low	Good	1
SC	Impervious	Good to fair	Low	Good	2
CL	Impervious	Fair	Medium	Good to fair	3
GM	Semi -impervious to impervious	Good	Negligible	Good	4
SM	Semi -impervious to impervious	Good	Low	Fair	5
ML	Semi- impervious to impervious	Fair	Medium	Fair	6
CH	Impervious	Poor	High	Poor	7

3 General description of the study area

3.1 General

The Tendaho Dam - Irrigation Project is situated in the Lower Awash valley in the afar Regional State in the North Eastern part of Ethiopia. The dam is located at 600 Km from Addis Ababa. Tendaho dam - Irrigation Project is designed to irrigate about 60,000 hectares of land at the Dubti, Dat- Bahri, and Assaiyita and Afambo areas for sugarcane plantation. This requires the construction of a 44m high (above river bed), 412 m long earth fill dam across the Awash River, and a spillway having a capacity of 1900m^3/sec and intake/outlet structures [18].

A main canal which has a length of about 72 kms takes irrigation water from the Tendaho dam and delivers it to the irrigation areas through several field canals. The first 17.8 km length of the main canal is not delivering water to the irrigation system. It is running free from Tendaho dam until the 1st off take at Dubti irrigation area.

3.2 Climate

Tendaho dam area is a low land and a very hot area located in the arid zone of the country. Temperature and rainfall recordings are available only at one location, at Dubti. Accordingly, the mean maximum temperature recorded at Dubti ranges from 32.1^{0}C - 42.1^{0}C and mean minimum temperature as 15.5-24.9^{0}C. The hottest months are from March to October and the coldest months from November to February. Mean monthly rainfall at the area (recorded at Dubti) ranges from 3.9-57.7mm. March, April, July and August receive more rainfall [18].

3.3 Geology of the dam area

The Tendaho Dam site is located within an area known as the 'Tendaho' which forms the centre of the Afar triangle, a low lying area of land, where the East African, the Red sea and the Gulf of Eden Rift systems converge.

This area is filled by various types of sedimentary deposits ranging from clay to gravel, volcanic tuffs, and hot spring deposits. The Pleistocene age sediments in the area consist of marine and lacustrine clays, silts, sandstones, siltstones, mudstones and conglomerates.

The bedrocks underlying the sedimentary rocks are Pleistocene age flood basalts belonging to the Afar group of the Ethiopian volcanic series [18].

3.4 Proposed Material sources

The geotechnical study report (July 2005) for the Tendaho dam and irrigation project states that sixteen material sources were identified as possible potential areas. Out of these, 14 were investigated and sampled, and the remaining two sources were identified as potential rock fill areas. Out of the 16 material source areas, three areas are private areas that supply sand and building stone for construction works in the locality.

Three locations are selected as potential sources for the core material (Area 2, Area 5, and Area 9). The laboratory tests on samples collected from these areas indicate the available material for the core of the dam is a highly plastic clay (CH) soil.

The status of the project, when this study was conducted, was under construction of the cofferdam (Fig 3.1). The materials being used to construct the core are blended clays. The blending was done by mixing clay soils with sandy gravel materials (Fig 3.2). Yet, there is no any study conducted on the effects of blending as well as how the blending ratio was selected for Tendaho dam. Although Tendaho dam is taken as a case study here, the useful findings of this thesis can be used as guidelines in other dam construction projects.

Figure3.1: Coffer dam under construction

Figure3.2: Material site: **a)** borrow area for clay core, and **b)** for sandy gravel shell.

4 LABORATORY TESTS AND RESULTS

4.1 Index Properties

4.1.1 General

Related ASTM standard were used in tests performed to determine the index properties of the materials. The purpose of conducting tests to determine the index properties is to determine their physical properties mainly for identification and classification purposes. The various properties of soils, which could be considered as index properties are specific gravity, grain size, free swell, and Atterberg limits.

4.1.2 Grain Size Analysis

This test method covers the quantitative determination of the distribution of particle sizes in the soils. The distribution of particle sizes larger than 75µm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75µm is determined using hydrometer analysis. To engineers engaged in the design and construction of earthwork for dam, the physical properties of soils such as unit weight, permeability, shear strength, and compressibility, and their interaction with water are of primary concern. It is advantageous to have a standard method of identifying soils and classifying them into groups that have distinct engineering properties.

ASTM D422-63 standard were used in tests performed to determine the grain size analysis of the samples under investigation and the results are presented in tables and figures. Figure 4.1 & Table 4.1 shows the grain size distribution curves and test results for the proposed naturally available core materials. Using USCS all the soil samples are categorized as fine grained soils. The grain size analysis test results for selected coarse materials are shown in Table 4.1 & Figure 4.2. All the selected coarse materials except sample Area14-Zone G3 are well-graded gravely sand materials. Further classifications of coarse materials are presented in Table 4.2. Table 4.8 & Figure 4.6 give the grain size analysis test result for the mixed materials. All the mixed materials except the ratio 50/50 are classified as fine grained soils.

Table 4.1: Grain size analysis result for clay and selected coarse materials

Item No.	Location	Percentage			Soil Category (Using USCS)
		Gravel	sand	Fine	
1	Area -14, Zone-C_1	-	3.2	96.8	Fine grained soil
2	Area -14, Zone-C_2	-	7.0	93.0	Fine grained soil
3	Area -9, Zone-C_1	-	2.1	97.9	Fine grained soil
4	Area -9, Zone-C_2	-	1.7	98.3	Fine grained soil
5	Area -5, Zone-C_1	-	7.3	92.7	Fine grained soil
6	Area -5, Zone-C_2	-	12.1	87.9	Fine grained soil
7	Representative Average Clay	-	5.55	94.45	Fine grained soil
8	Area -14, Zone-G_1	41.61	57.49	0.9	Coarse grained soil
9	Area -14, Zone-G_2	41.61	57.39	1.0	Coarse grained soil
10	Area -14, Zone-G_3	50.28	48.02	1.7	Coarse grained soil
11	Area -5, Zone-G_1	33.95	61.85	4.2	Coarse grained soil
12	Area -5, Zone-G_2	31.08	64.52	4.4	Coarse grained soil
13	Area -5, Zone-G_3	21.17	74.93	3.9	Coarse grained soil
14	Representative Average coarse material	36.32	60.88	2.80	Coarse grained soil

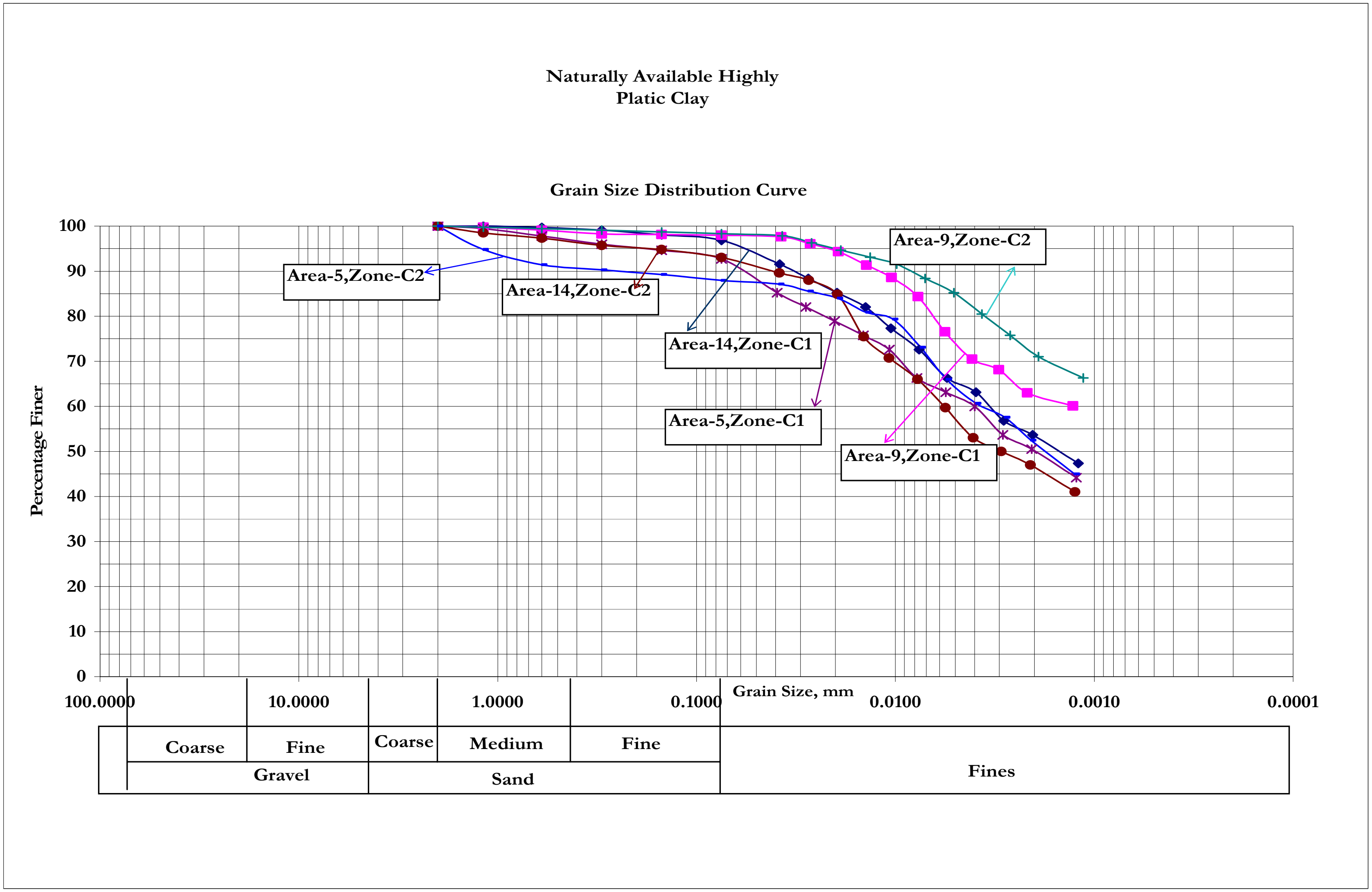


Figure 4.1: Grain size analysis curve for the naturally available fine materials

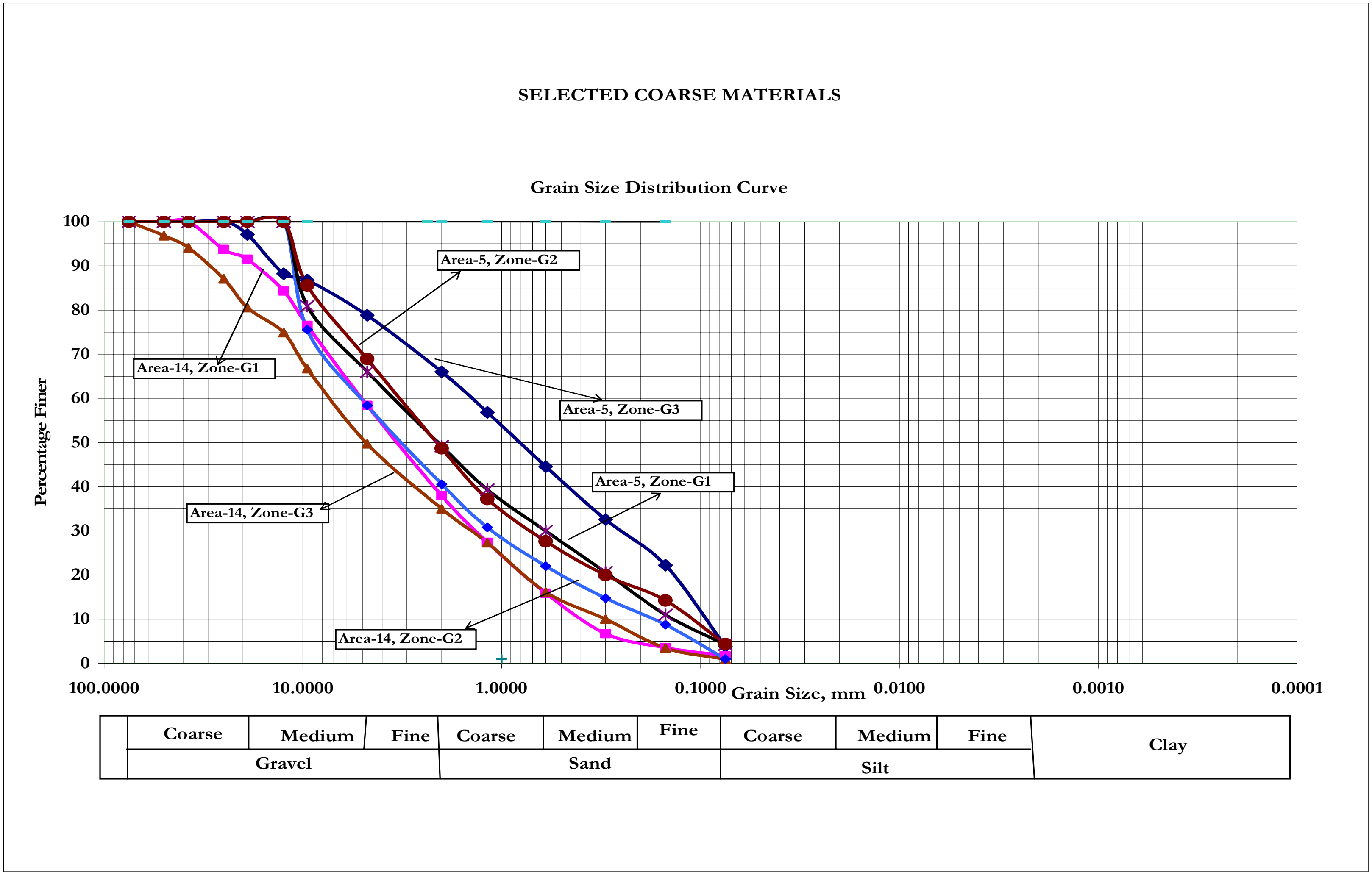


Figure 4.2: Grain size analysis curve for coarse Materials

Table 4.2: Classification of selected coarse-grained materials (using USCS).)

It. No	Location	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c	Soil Type	Soil Group Name (USCS)
1	Area -14, Zone-G_1	0.12	0.70	3.20	26.7	1.28	SW	Well - graded sand with gravel
2	Area -14, Zone-G_2	0.14	0.60	3.50	25	0.73	SP	Poorly - graded sand with gravel
3	Area -14, Zone-G_3	0.10	0.25	1.50	15	4.17	GP	Poorly - graded gravel with sand
4	Area -5, Zone-G_1	0.17	1.20	5.00	29.4	1.69	SW	Well - graded sand with gravel
5	Area -5, Zone-G_2	0.30	1.50	7.00	23.3	1.07	SW	Well - graded sand with gravel
6	Area -5, Zone-G_3	0.40	1.50	5.00	12.5	1.13	SW	Well - graded sand with gravel
5	Representative Average	0.15	0.80	4.00	26.7	1.07	SW	Well - graded sand with gravel

- This table is based on ASTM D-2487 designation [4].

4.1.3 Specific Gravity

The main purpose of determining the specific gravity of a soil here is for use in calculating the phase relationship of a soil during compaction (i.e. Zero air voids), in calculations in connection with hydrometer test analysis and to determine the void ratio during consolidation test analysis. This test method covers the determination of the specific gravity of soils that pass the 2.00mm (No.10) sieve. The specific gravity of soil samples under investigation was determined using ASTM D854-92 standard, and the results obtained are tabulated in Table 4.3 for highly plastic clay and Table 4.10 for mixed clay.

Table 4.3: Specific test results for fine materials

Item No.	Sample Location	Specific Gravity
1	Area -14, Zone-C_1	2.73
2	Area -14, Zone-C_2	2.75
3	Area -9, Zone-C_1	2.74
4	Area -9, Zone-C_2	2.70
5	Area -5, Zone-C_1	2.71
6	Area -5, Zone-C_2	2.69

4.1.4 Atterberg Limits

Atterberg limits are regarded as useful indices for determining the characteristics of most clay. This is true because parameters depend on the amount of water a soil tries to imbibe. A typical soil mass have three constituents: soil grains, air, and water. In soils consisting largely of fine grains, the amount of water present in the void has a pronounced effect on the soil properties.

In describing these soil states, it is customary to consider only a fraction of soil smaller than the No.40 (0.425mm) sieve size. For this soil fraction, the water content in percentage of dry weight at which the soil passes from the liquid state to the plastic state is called liquid limit. Similarly, the water content of the soil at the boundary between the plastic state and solid state is called the plastic limit. The difference between the liquid limit and the plastic limit corresponds to the range of water content within which the soil is plastic, and is called plasticity index (PI). Soils with high plasticity have high value of PI.

These limits of consistency, known as “Atterberg limits” are used in the plasticity chart as the basis in laboratory differentiation of materials of appreciable plasticity (clays) and slightly plastic or non-plastic materials (silts). Following ASTM D4318-95 standards, the test results obtained are tabulated in Table 4.5 for the fine materials. From the results shown all the materials are highly plastic inorganic clays. Table 4.9 gives the Atterberg results obtained for the mixed clay. It has been found that the mixed materials 10/90 & 20/80 are CH soils and the mixed materials 30/70 & 40/60 are CL group. Figure 4.3 and 4.4 show the positions of highly plastic clays plotted in the plasticity chart and swelling potential chart, respectively.

Table 4.5: Atterberg limit test results for fine grained soils

Item No.	Sample Location	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Soil Type Using USCS	Soil Group Name (USCS)
1	Area -14, Zone-C_1	78.6	33.77	44.83	CH	Fat clay
2	Area -14, Zone-C_2	52.5	23.08	29.42	CH	Fat clay
3	Area -9, Zone-C1	78.2	34.45	43.75	CH	Fat clay
4	Area -9, Zone-C_2	56.9	25.52	31.38	CH	Fat clay
5	Area -5, Zone-C_1	71.0	32.54	38.46	CH	Fat clay
6	Area -5, Zone-C_2	61.4	31.05	30.35	CH	Fat clay

➢ This table is based on ASTM D-2487 designation [4].

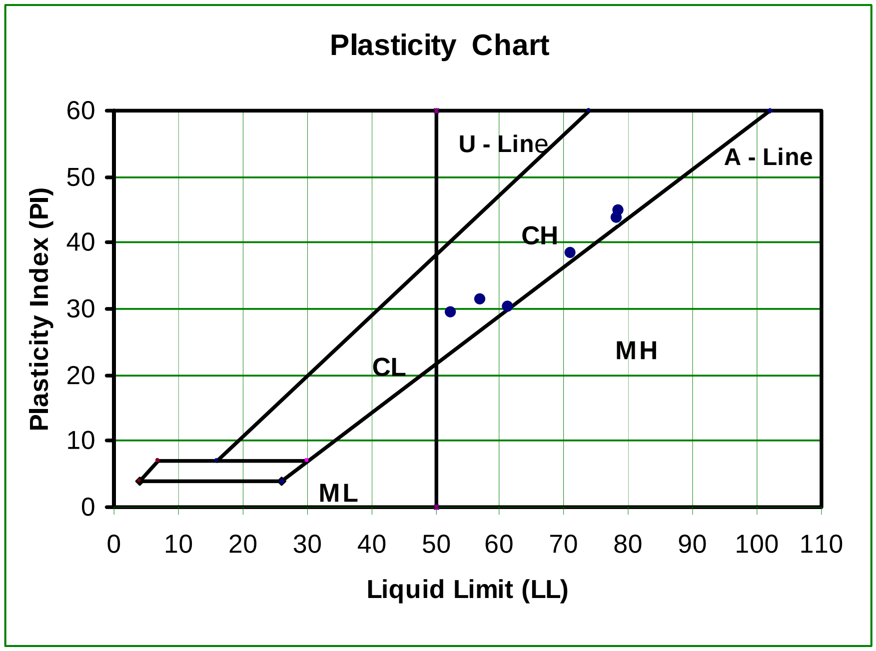


Figure 4.3: Samples of fine grained soils on Plasticity Chart

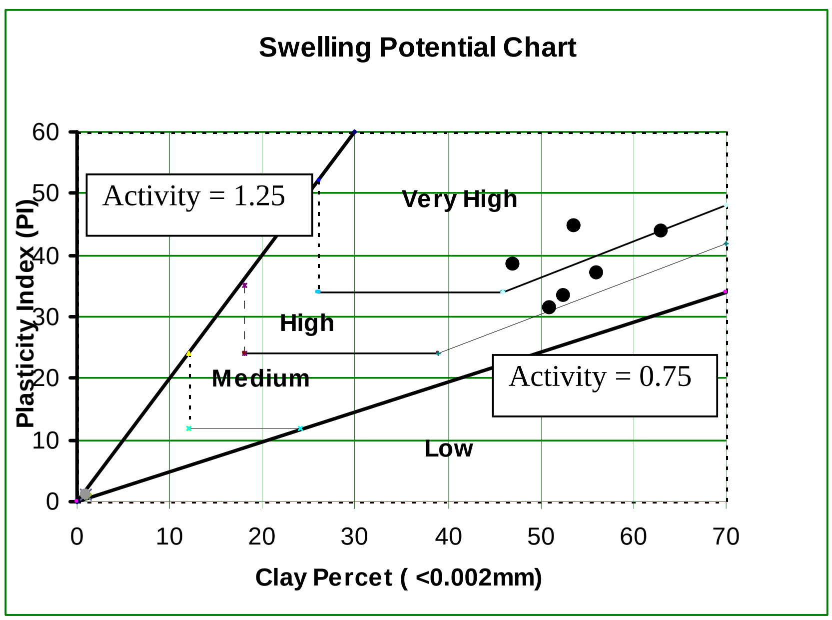


Figure 4.4: Samples of fine grained soils on Williams and Donaldson (1980)'s swelling potential Chart

4.2 Compaction Test

This test method covers laboratory compaction procedures used to determine the relationship between water content and dry unit weights of soils. Soils to be placed as embankment core materials are compacted to a dense state to obtain satisfactory engineering properties such as, shear strength, compressibility and permeability. Laboratory compaction tests provide the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure the required compaction and water contents are achieved. Consolidation, Shear, and permeability of embankment core materials require preparation of test specimens by compacting at some water content and some unit weight. It is common practice to first determine the optimum water content and maximum dry unit weight by means of compaction test

For the soil under investigation, the standard proctor compaction test was used following ASTM D698 standard to determine the compaction parameters as maximum dry density and optimum water content. By using the data obtained from the compaction tests, compaction curves were plotted, and by using these curves values of maximum dry unit weight and optimum water content were found as shown in Table 4.6 for highly plastic clays and Table 4.11 for mixed clays. After obtaining an experimental compaction curve, the 100% saturation curves (zero air voids) were plotted for each material.

Table 4.6: Proctor test results for highly plastic clay

Item No.	Sample Location	MDD	OMC
1	Area -14, Zone-C_1	1.33	30.2
2	Area -14, Zone-C_2	1.377	29.5
3	Area -9, Zone-C_1	1.338	32.5
4	Area -9, Zone-C_2	1.34	32.0
5	Area -5, Zone-C_1	1.285	34.0
6	Area -5, Zone-C_2	1.38	27.3

4.3 Permeability Tests

This test method covers the determination of the coefficient of permeability of a soil under investigation. The permeability of the soil in a dam embankment is a fundamental property but depends on a number of factors. Head (1985) outlines these as: particle size distribution; particle shape; mineralogical composition; void ratio; degree of saturation. In embankment dam engineering these factors have varying degree of influence [14]:

The void ratio of a soil has an important effect on permeability. Cohesive soils which are compacted on a high density ratio will have lower permeability than those compacted to a low density ratio. The void ratio also has an effect on the permeability of granular soils, with soils compacted to a small void ratio (dense) having lower permeability than those with a high void ratio (loose). The permeability classification according to Head (1985), permeability less than 10^{-7} cm/sec are practically impermeable. The permeability of the samples taken was determined from the falling head permeability tests following ASTM D-2434 standard performed on each compacted samples. The permeability coefficients obtained from the tests for naturally available highly plastic clay is $6x10^{-9}$ cm/s and that of mixed clay is presented in Table 4.12 and are plotted as shown Fig 5.3. The ranges of the materials permeability are varying from low permeability to impervious soils.

4.4 TYPE AND METHOD OF PREPARATION OF THE MIXED CLAY

As explained earlier, the type of the clay material used in this study is collected from different parts in the borrow areas in Tendaho Dam. These materials are highly plastic and highly expansive with LL = 52%-79% and PI = 20%-45%, free swell =110%-145%. The average specific gravity of these materials is about 2.72 (Tables 4.3 - 4.5). The coarse material added to the clay, is sandy gravel ***(SW)*** (Table 4.2). The Cu and Cc parameters of the material are 26.7 & 1.07 respectively. The ranges of the particle size distribution of the cohesive and granular materials, which are available and used in the test together with the average selected material used in this study, are shown in Figure 4.5.

For laboratory testing, considering the diameter of the specimens, the large sizes of the coarse material, which are not allowed to be in the specimen, are initially removed. The blending should be done in such away that the water tightness and other required properties of the fine grained soils are appreciably maintained and improvement in the gradation is achieved. Then the two types of the materials are homogenously mixed with each other based on the desired percentage of combination. For covering the possible ranges of the mixed materials, five combinations of soils of gravely sand to highly plastic soils **(i.e. SW/CH)**, namely; **10/90, 20/80, 30/70, 40/60, and 50/50** by volume were selected and used for laboratory testing.

Following the same test procedure done for the naturally available highly plastic clay, the test results for the mixed clay are tabulated in tables and figures as shown below.

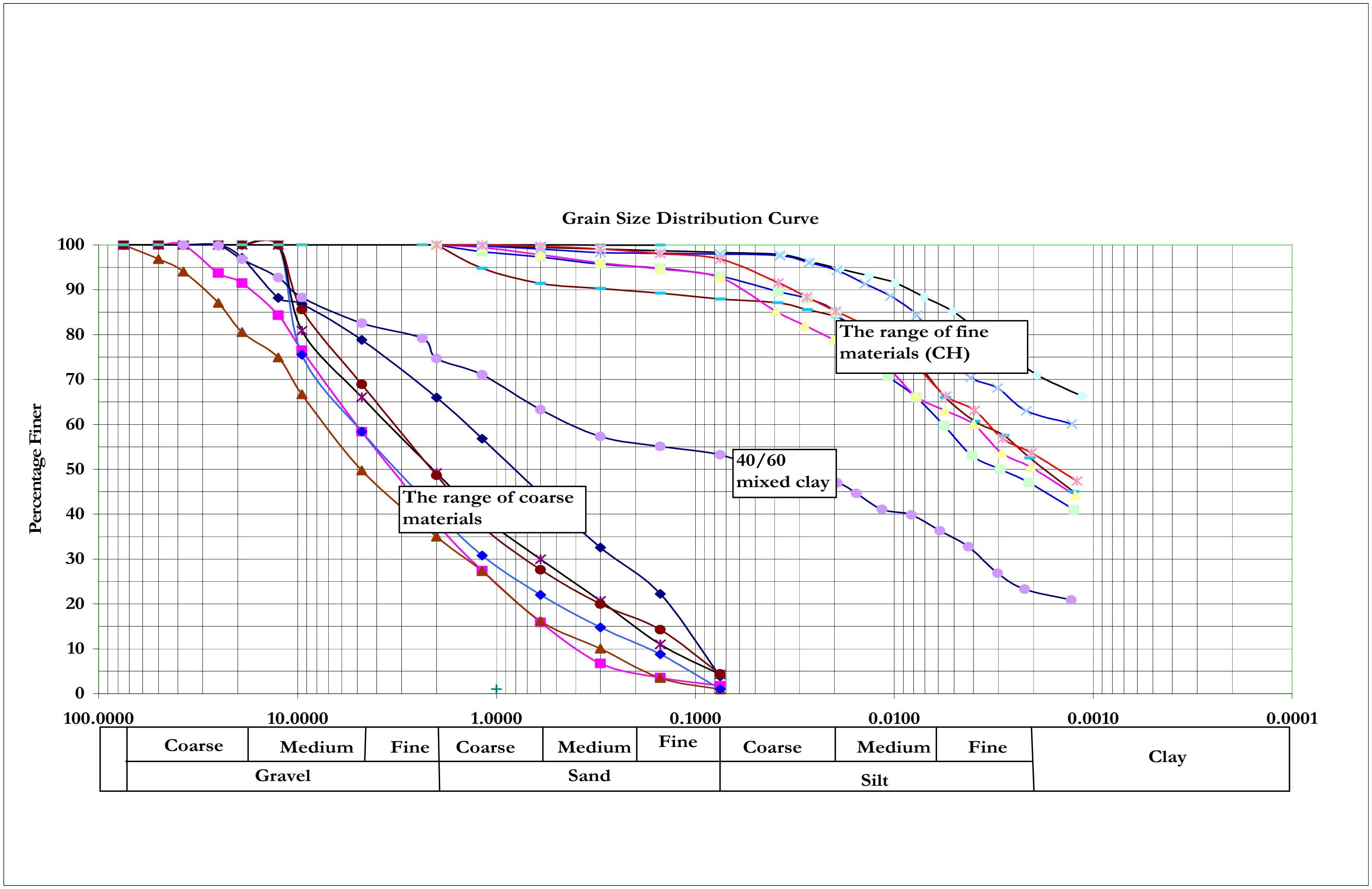


Figure 4.5: Ranges of particle size distributions of coarse and fine materials in the study area with *mixed-clay*.

4.4.1 Grain Size Analysis

Table 4.7: Grain size analysis result for mixed clay

Item No.	Mixed sample	Percentage			Soil Category (USCS)
		Gravel	sand	Fine	
1	10%SW & 90%CH	1.90	8.9	89.20	Fine grained soil
2	20%SW & 80%CH	11.64	10.94	77.42	Fine grained soil
3	30%SW & 70%CH	14.55	19.44	66.01	Fine grained soil
4	40%SW & 60%CH	17.47	29.34	53.19	Fine grained soil
5	50%SW & 50%CH	20.35	39.28	40.37	Coarse grained soil

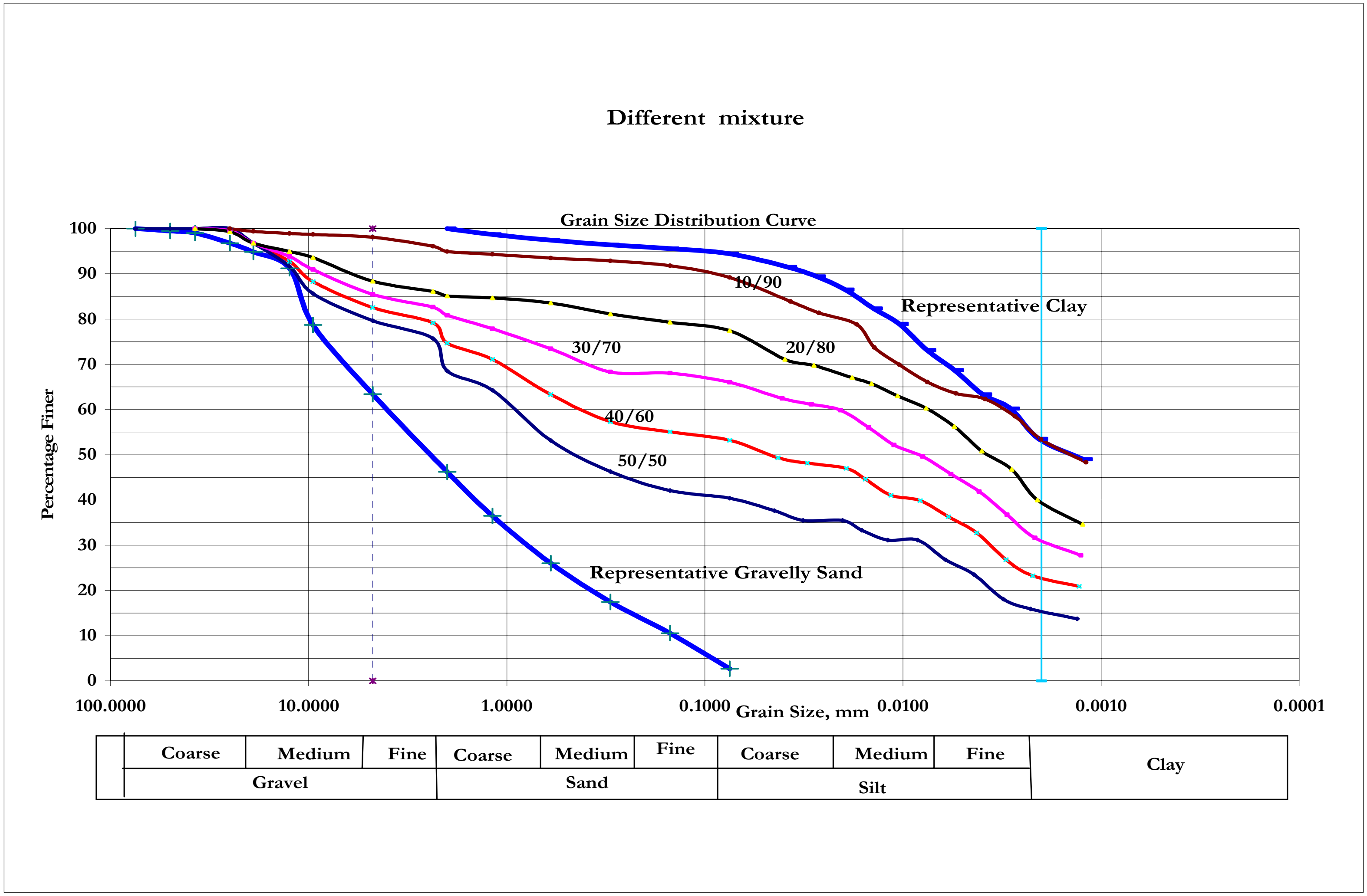


Figure 4.6: Grain size analysis curve for mixed clay

According to USCS, all the mixed materials except 50/50 are classified as fine grained soils. Further classifications of these mixed fine grained soils are shown in Table 4.12. The mixed coarse material 50/50 belongs to SM group as shown in Table 4.9..

Table 4.8: Classifying of coarse grained mixture materials using Unified Soil Classification System (USCS).

It. No	**Mixed sample**	**D_{10} (mm)**	**D_{30} (mm)**	**D_{60} (mm)**	**C_u**	**C_c**	**Soil Type**	**Soil group name**
1	50%SW & 50%CH	0.001	0.006	0.90	900	0.40	SM	Silty Sand with gravel

4.4.2 Specific Gravity

Table 4.9: Specific gravity test results for mixed clay

Item No.	Mixed sample	Specific Gravity
1	10%SW & 90%CH	2.70
2	20%SW & 80%CH	2.73
3	30%SW & 70%CH	2.70
4	40%SW & 60%CH	2.74
5	50%SW & 50%CH	2.78

4.4.3 Atterberg Limits

The following table is based on ASTM D-2487 designation.

Table 4.10: Atterberg limit test results for mixed clay

Item No.	Mixed Sample	Liquid limit (%)	Plasticity index (%)	Soil Type Using USCS	Soil Group Name (USCS)
1	10%SW & 90%CH	57.11	35.96	CH	Fat clay
2	20%SW & 80%CH	53.30	24.45	CH	Fat clay
3	30%SW & 70%CH	46.50	21.17	CL	Sandy Lean clay
4	40%SW & 60%CH	41.1	18.58	CL	Sandy Lean clay with gravel
5	50%SW & 50%CH	40.6	14.2	SM	Silty sand with gravel

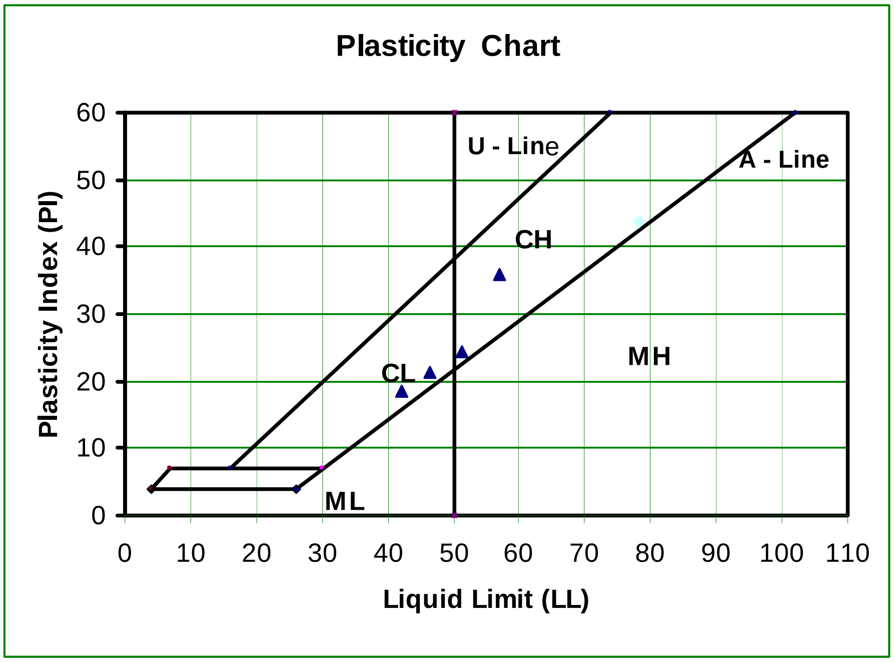


Figure 4.7: Plasticity Chart for mixed clay

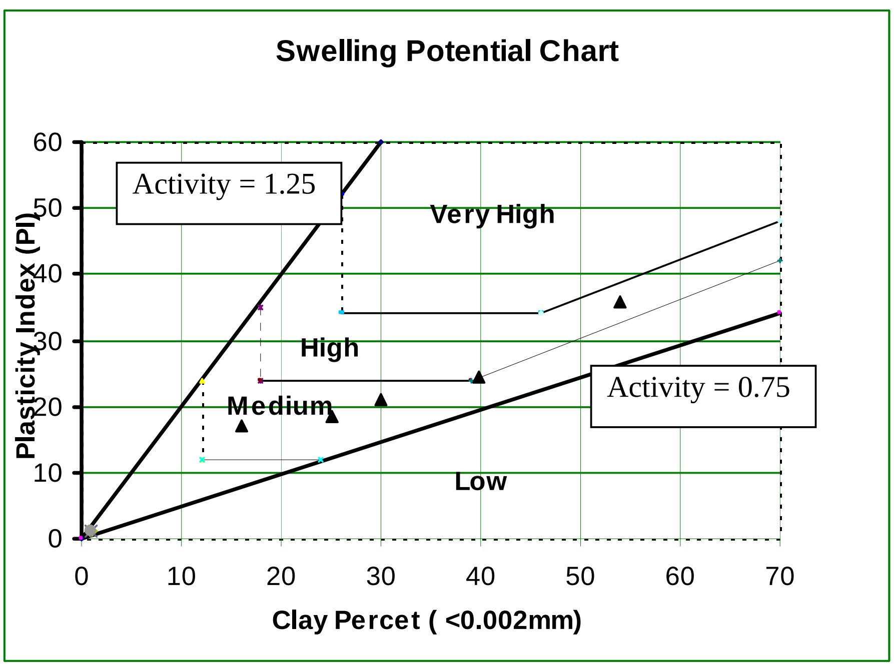


Figure 4.8: Williams and Donaldson (1980)'s Swelling potential Chart for mixed clay

4.4.4 Compaction Test

Table 4.11: Proctor test results for mixed clay

Item No.	Mixed sample	MDD	OMC
1	10%SW & 90%CH	1.453	23.6
2	20%SW & 80%CH	1.501	19.0
3	30%SW & 70%CH	1.566	18.8
4	40%SW & 60%CH	1.61	16.0
5	50%SW & 50%CH	1.653	16.3

4.4.5 Permeability Tests

Table 4.12: Permeability test results and Permeability classification according to Head (1985)

Item No.	**Soil Type**	**Coefficient of permeability, K (cm/sec)**	**Permeability classification, (Using Head, 1985)**
1	Pure plastic clay	$6 * 10^{-9}$	Practically Impermeable
2	Mixed Clay (10/90)	$2.93 * 10^{-8}$	Practically Impermeable
3	Mixed Clay (20/80)	$3.7 * 10^{-8}$	Practically Impermeable
4	Mixed Clay (30/70)	$5.1 * 10^{-8}$	Practically Impermeable
5	Mixed Clay (40/60)	$1.29 * 10^{-7}$	Very low permeability
6	Mixed Clay (50/50)	$5.98 * 10^{-7}$	Very low permeability

4.5 Additional tests

4.5.1 1D - Consolidation Tests

The purpose of conducting this test here is to study and compare the compressibility characteristics of the pure and mixed clays. This test method covers procedures for determining the magnitude and rate of compression of a soil when it is restrained laterally and drained axially while subjected to incrementally applied controlled–stress loading. In this test, the data from the consolidation test recorded were the changes in specimen height and these data are used to determine the relationship between the effective stress and void ratio. The tests were conducted following ASTM D-2435-90 standard and the results are as shown in fig 4.9

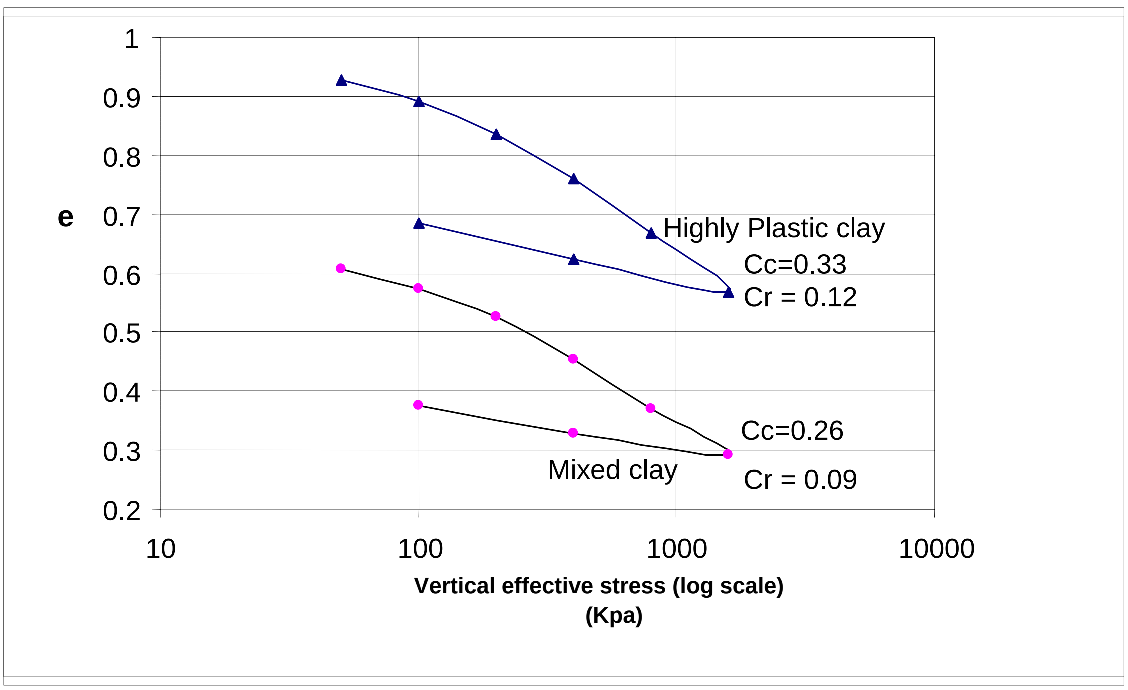


Figure 4.9: Void ratio Vs Vertical effective stress

4.5.2 Triaxial tests (UU)

In this study, the main purpose of conducting triaxial test is to see the stress- strain behavior of the soils under investigations. This leads us to compare the stiffness characteristics of pure clay to that of mixed clay as shown in Fig 4.10. It should be noted that it was not possible to conduct CU and CD tests because the triaxial compression apparatus available has some serious problems. Even the UU tests shown below were conducted in the construction Design Enterprise Share Company at some additional costs.

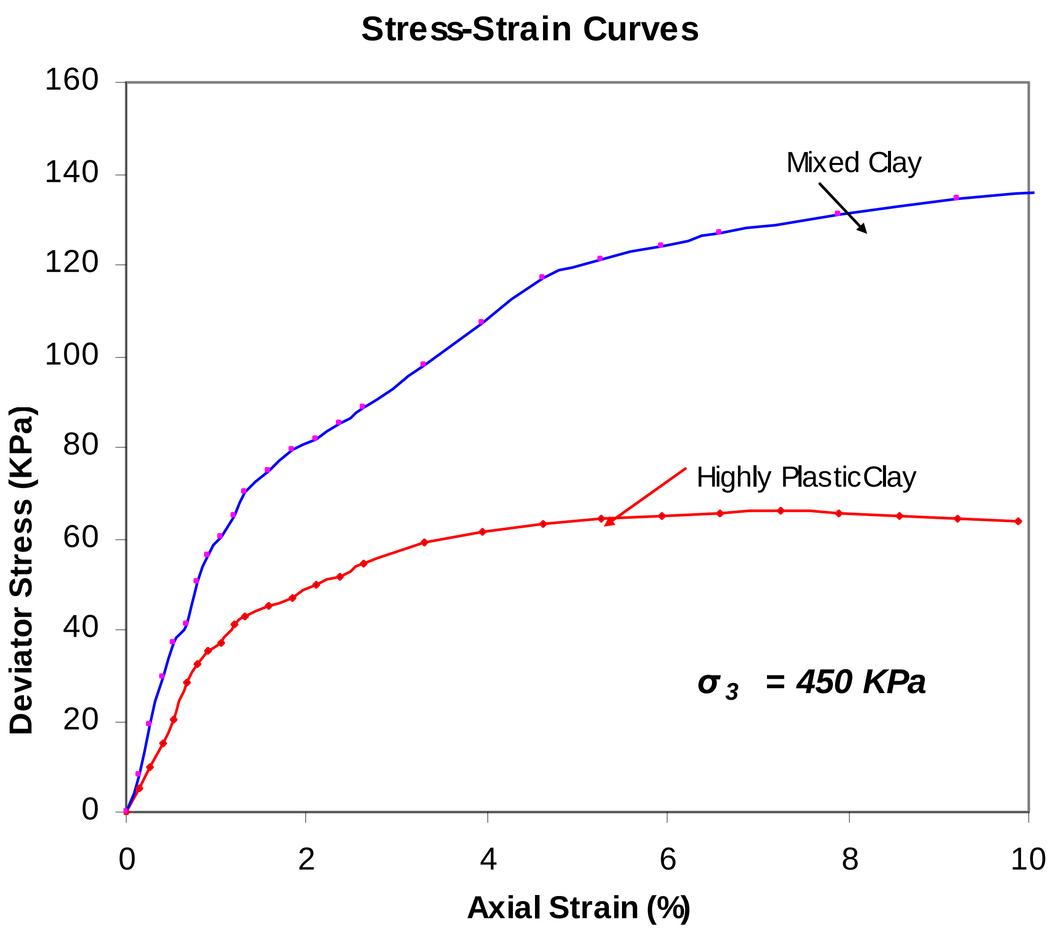


Figure 4.10: Deviator Stress Vs Axial Strain relationship

4.5.3 Filter criteria

The purpose of evaluating filter criteria here is to see the effect of blending gravely sand materials on highly plastic clays.

Where the difference in coarseness between the finer and the coarser of the embankment zones is too great to meet filter criteria, zones of intermediate gradation must be provided. These are constructed of sands and gravels with special gradation characteristics and are called filters.

Filters in embankment dams are required to perform two basic functions:

a) Prevent erosion of soil particles from the soil they by protecting
b) Allow drainage of seepage water

Filters are usually specified in terms of their particle size distribution. They are required to be sufficiently fine relative to the particle size of the soil they are protecting (the “base soil”), to achieve function (a), while being sufficiently coarse to achieve function (b).

The recommended method for the design of filters in embankment dams is based on Sherard and Dunnigan (1985, 1989). Using the filtering criteria, permeability criteria, segregation criteria and other criteria’s set by Sherard and Dunnigan (1985, 1989) (Appendix-A), the required filter materials are shown in figure 4.11 and 4.12, for naturally available highly plastic clay and mixed clay, respectively.

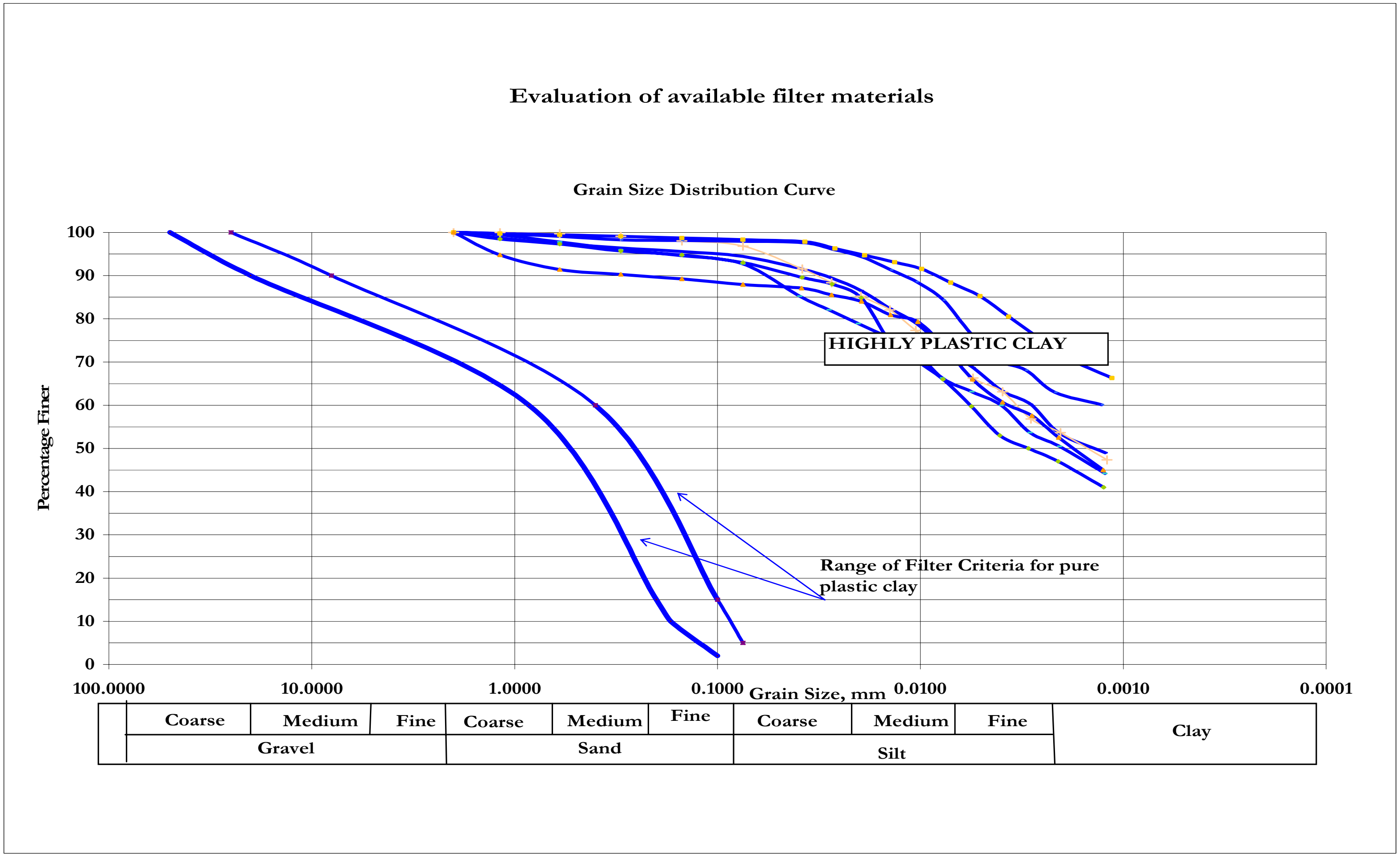


Fig 4.11: Range of required filter material for highly plastic clay

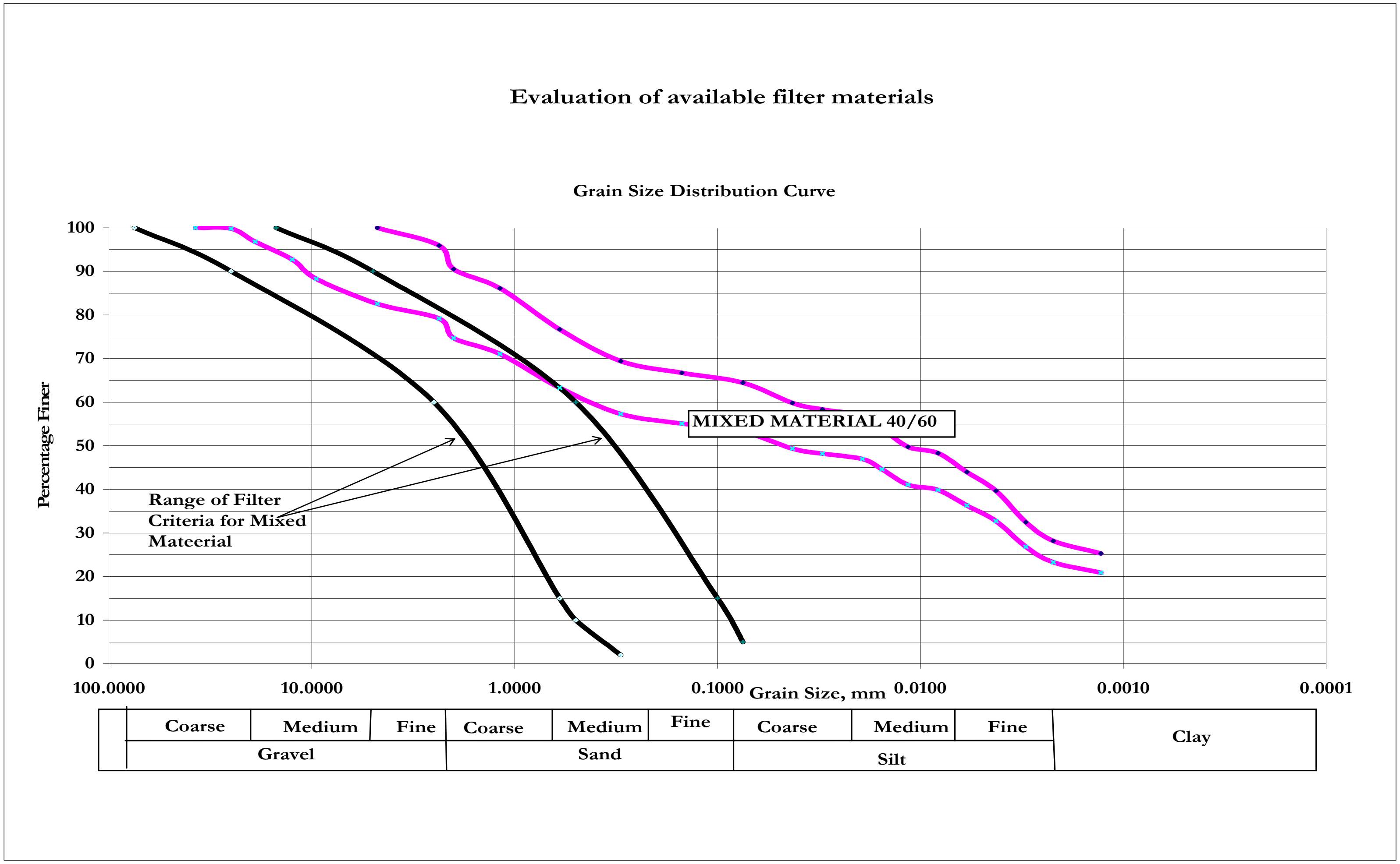


Fig 4.12: Range of required filter material for mixed clay

TABLE4.21 : SUMMARY OF LABORATORY TEST RESULTS

Sr.No.	LOCATION	Sp.Gr	Grain Size Distribution			Atterberg's Limits		Compaction		Permeability	Consolidation		Remarks
			Gravel	Sand	Fines	WL	PI	MDD	OMC	cm/sec	Cc	Cr	
1	Area -14,Zone-C1	2.73	-	3.2	96.8	78.6	44.83	1.33	30.2	$6*10^{[illegible]}$	0.33	0.12	CH
2	Area -14,Zone-C2	2.75	-	7	93	52.5	29.42	1.377	29.5				CH
3	Area -9,Zone-C1	2.74	-	2.1	97.9	78.2	43.75	1.338	32.5				CH
4	Area -9,Zone-C2	2.7	-	1.7	98.3	56.9	31.38	1.34	32				CH
5	Area -5,Zone-C1	2.71	-	7.3	92.7	71	38.46	1.285	34				CH
6	Area -5,Zone-C2	2.69	-	12.1	87.9	61.4	30.35	1.38	27.3				CH
7	Area -14,Zone-G1	-	41.6	57.49	0.9	-	-	-	-	-	-	-	SW
8	Area -14,Zone-G2	-	41.61	57.39	1	-	-	-	-	-	-	-	SP
9	Area -14,Zone-G3	-	50.28	48.02	1.7	-	-	-	-	-	-	-	GP
10	Area -5,Zone-G1	-	33.95	61.85	4.2	-	-	-	-	-	-	-	SW
11	Area -5,Zone-G2	-	31.08	64.52	4.4	-	-	-	-	-	-	-	SW
12	Area -5,Zone-G3	-	21.17	74.93	3.9	-	-	-	-	-	-	-	SW
13	10%SW & 90% CH	2.7	1.9	8.9	89.2	57.11	35.96	1.453	23.6	$0.290*10^{-7}$	-	-	CH
14	20%SW & 80% CH	2.73	11.64	10.94	77.4	51.3	24.45	1.501	19	$0370*10^{-7}$	-	-	CH
15	30%SW & 70% CH	2.7	14.55	19.44	66.01	46.5	21.17	1.566	18.8	$0.510*10^{-7}$	-	-	CL
16	40%SW & 60% CH	2.74	17.47	29.34	53.2	42.1	18.58	1.61	16	$1.290*10^{-7}$	0.26	0.09	CL
17	50% SW & 50% CH	2.78	20.36	39.28	40.373	40.6	14.2	1.653	16.3	$5.980*10^{-7}$	-	-	SM

5 DISCUSSIONS ON LABORATORY TEST RESULTS

5.1 Characteristics of the mixed clay in comparison with naturally available highly plastic clay

Different laboratory tests were carried out to obtain the properties of the mixed clays used and to study the influence of the added coarse material on the plastic clays. The appropriate percentage of the clay/gravely sand combination was selected using the conditions:

- ❖ The coefficient of permeability of the mixed clay remains in an acceptable limit (After Head 1985) [6].
- ❖ The mixed clay must be out of CH group (preferably its relative desirability as impervious core of embankment material is greater or equal to that of CL soil.) according to the plasticity chart (U.S.B.R., 1974) and Engineering use of chart.
- ❖ The mixed material has to satisfy the limits of the index properties to be used in clay core of earth dams (After Yilmaz and Karacan (1996**)).**

5.1.1 Index Properties

According to the results obtained from the grain size analyses of the samples (CH soils, mixed materials), all the materials except the 50/50 mixed clay were determined as fine-grained as shown in Figure 4.1, Table 4.1, Figure 4.6, Table 4.7 and Table 4.8.

The entire test results obtained for naturally available highly plastic clays as shown in Table 5.1, with the exception of the specific gravity, is over the limits suggested (After Yilmaz and Karacan, 1996) for the materials to be used in the clay core. 10/90 and 20/80 mixed materials are also failed to satisfy the limits suggested by Yilmaz and Karacan, 1996.

According to USCS and the plasticity chart (U.S.B.R., 1974) the mixed materials 10/90 & 20/80 are grouped as CH (high plasticity, inorganic clay) (Figure 5.1), while the mixed materials30/70, 40/60 are CL group, and the 50/50 is SM group (Table 4.8 and Table 4.10).

According to Williams and Donaldson (1980)'s swelling potential chart (Figure 5.2) CH materials provide very high swelling potential, these values range from high to very high.

This swelling potential of the materials causes the problems in using as impervious material in the clay core. All the above drawbacks restrict the usefulness of the mixed materials 10/90, 20/80, and 30/70.

Table 5.1: Test results of index properties

Descriptions	**Limit Values**	**CH Soils Average Value**	**Mixed Clay (SW / CH Ratio)**				
			10./90	**20/80**	**30/70**	**40/60**	**50/50**
Specific Gravity, Gs	>2.6	2.72	2.7	2.73	2.7	2.74	2.78
Max, Dry unit weight, g_{dmax},g/cm	>1.6	1.34	1.45	1.5	1.57	1.61	1.65
Opt. water content, $w_{opt,}$ %	15-20	30.92	23.6	19	18.8	16	16.3
Liquid Limit, wL,%	40-50	66.43	52.1	51.3	46.5	42.1	40.6
Plasticity index ,Ip,%	14-20	36.37	31	24.45	21.17	18.6	14.2

❖ The limit values are obtained from Yilmaz and Karacan (1996**).**

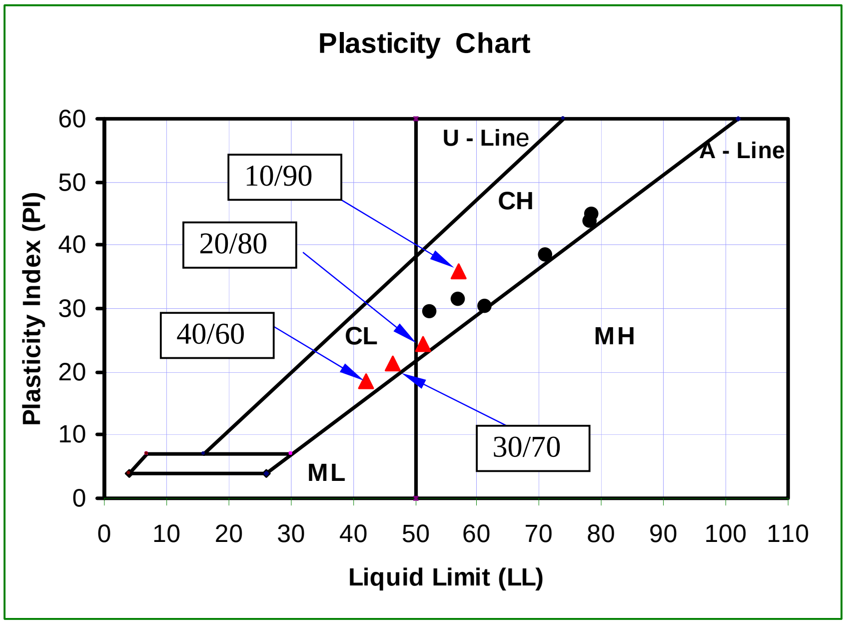


Figure 5.1: Distribution of all the samples on the plasticity chart.

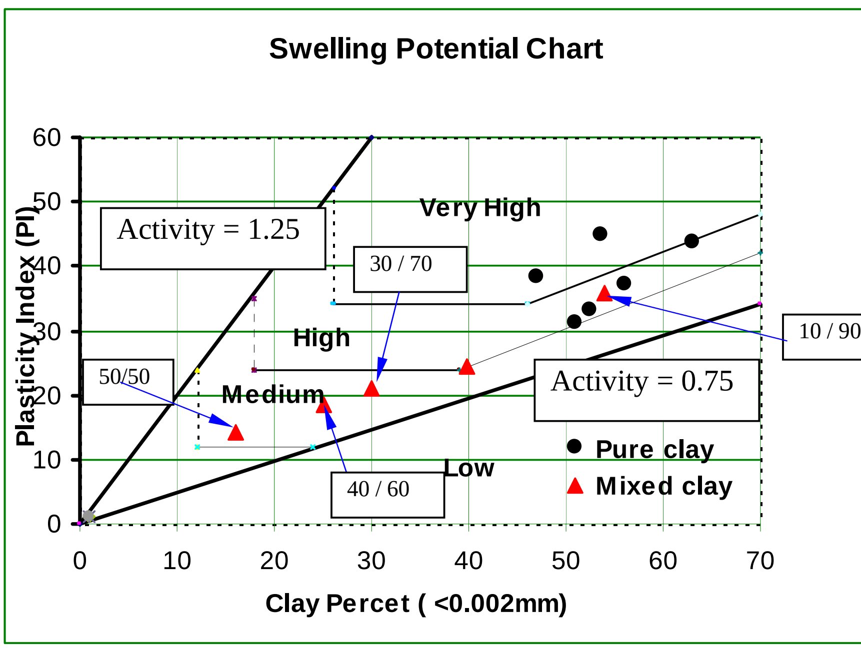


Fig 5.2: Distribution of all the samples on Williams and Donaldson (1980)'s swelling potential chart.

5.1.2 Compaction Properties

The most suitable case of this compaction is obtained at the water content, known as the optimum water content, at which a maximum dry unit weight is reached.

The maximum dry unit weight value of the 30/70 mixed material is found to be 1.57gm/cm^3 (Table 5.1), which is below the limits (1.6 gm/cm^3) suggested for material to be used in the impervious clay core (After Yilmaz and Karacan, 1996). Thus, this draw back restricts the usefulness of the mixed material 30/70.

5.1.3 Permeability

Prior to the selection of the optimum mixture, some permeability tests were carried out on different mixed clays and the effect of adding gravelly sand on the coefficient of permeability of the clay was studied The permeability of the plastic clays and mixed clays taken was determined from the falling head permeability tests (ASTM D-2434) performed on each compacted samples. The permeability coefficients obtained from the results of these tests varied from 5.98x10^{-7} cm/s to 6x10^{-9} cm/s and the results are plotted as shown below.

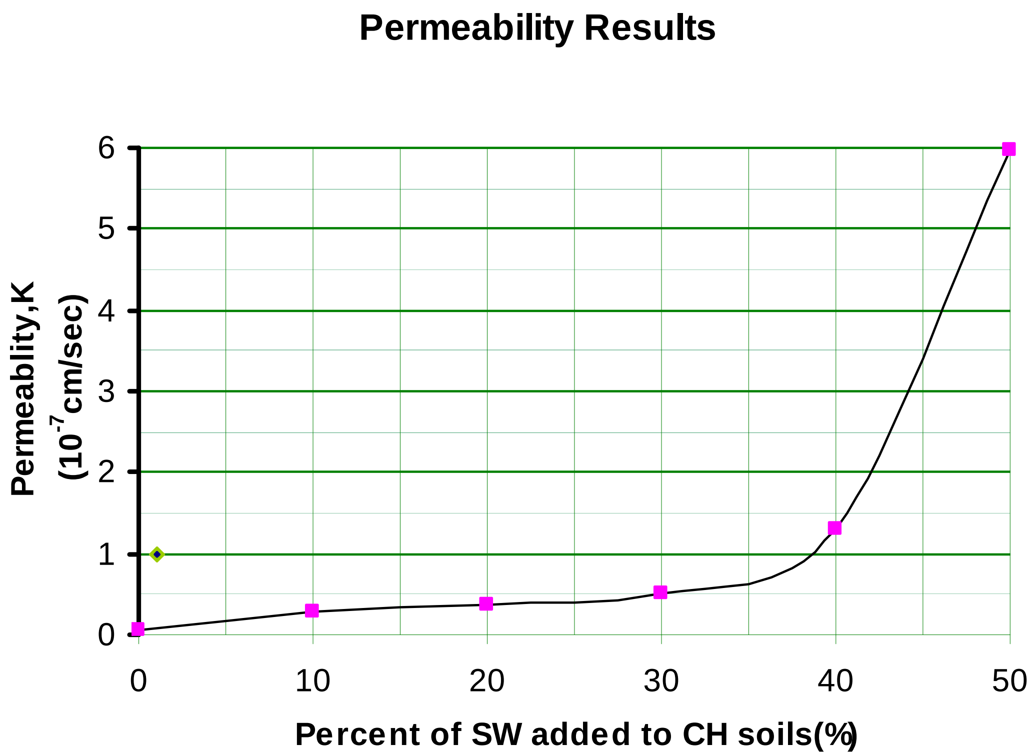


Figure 5.3 The results of permeability tests on the *mixed-clay* used.

According to these permeability values obtained, materials are placed in the very low permeable to impermeable class (After Bell 1985). The optimum mixture percentage in which neither the material becomes too permeable nor remains too soft, and from the point of relative desirability for core material (After Wagner), 40/60 (group of CL) is more desirable than and 50/50 (group of SM). The 40/60 ratio is suitable for impermeable clay core in soil embankment dams.

5.2 Additional test results

Based on different tests carried out on the mixed clay specimens of above mixture (i.e.: 60% highly plastic clay + 40% gravelly sand), additional tests were carried out for both highly plastic clay and the mixed clay. The results of the experiments are plotted for both CH soils and mixed samples.

5.2.1 Consolidation Characteristics

As can be seen from the Figure 4.9 the initial void ratio of the highly plastic clay is greater than that of mixed clay. For a change in loading from 50KPa to 100KPa the change in void ratio of the pure plastic clay is 0.36 (i.e. from 0.928 to0.568), which is higher than that of the mixed clay of 0.308 (i.e. from 0.608 to 0.3). The compression index, Cc, for the highly plastic clay is 0.33 and that of mixed clay is 0.26, which implies that the response of clay core to compression constructed of using highly plastic clay is greater than that of mixed clay. Hence the compressibility property of highly plastic clay is improved considerably when it is mixed with sandy gravel.

5.2.2 Stress – Strain relations

In order to compare the stiffness and deformation behaviour of the highly plastic clay with that of mixed clay, the results of triaxial compression (UU) are plotted for both pure and mixed samples in the same graph. As can be seen from Figure 4.10, the mixed sample shows stronger and stiffer behaviours than the highly plastic clay sample**.** Hence the stiffness property of highly plastic clay is improved considerably when it is mixed with gravely sand.

5.2.3 Filter requirements

As can be seen from figure 5.4 & 5.5 the required filter materials as the transition zone between the core and the shell has been relatively finer in the highly plastic clay than the mixed clay. Besides the available filter gradation at the site is out of the range of the required for the highly plastic clay. This restricts the use of the available filter in the highly plastic clay impervious core. Where as the available filter gradation is with in the range of the required filter for mixed clay, this allows the use of the available filter in the mixed clay impervious core. In general the ranges for the filter material to be used are greater in the mixed clay (i.e. it gives freedom for production or selection of filter materials). Hence mixing of gravely sand to the highly plastic clay increases the ranges for the selection of the filter and increases the size of gradation of the filter material.

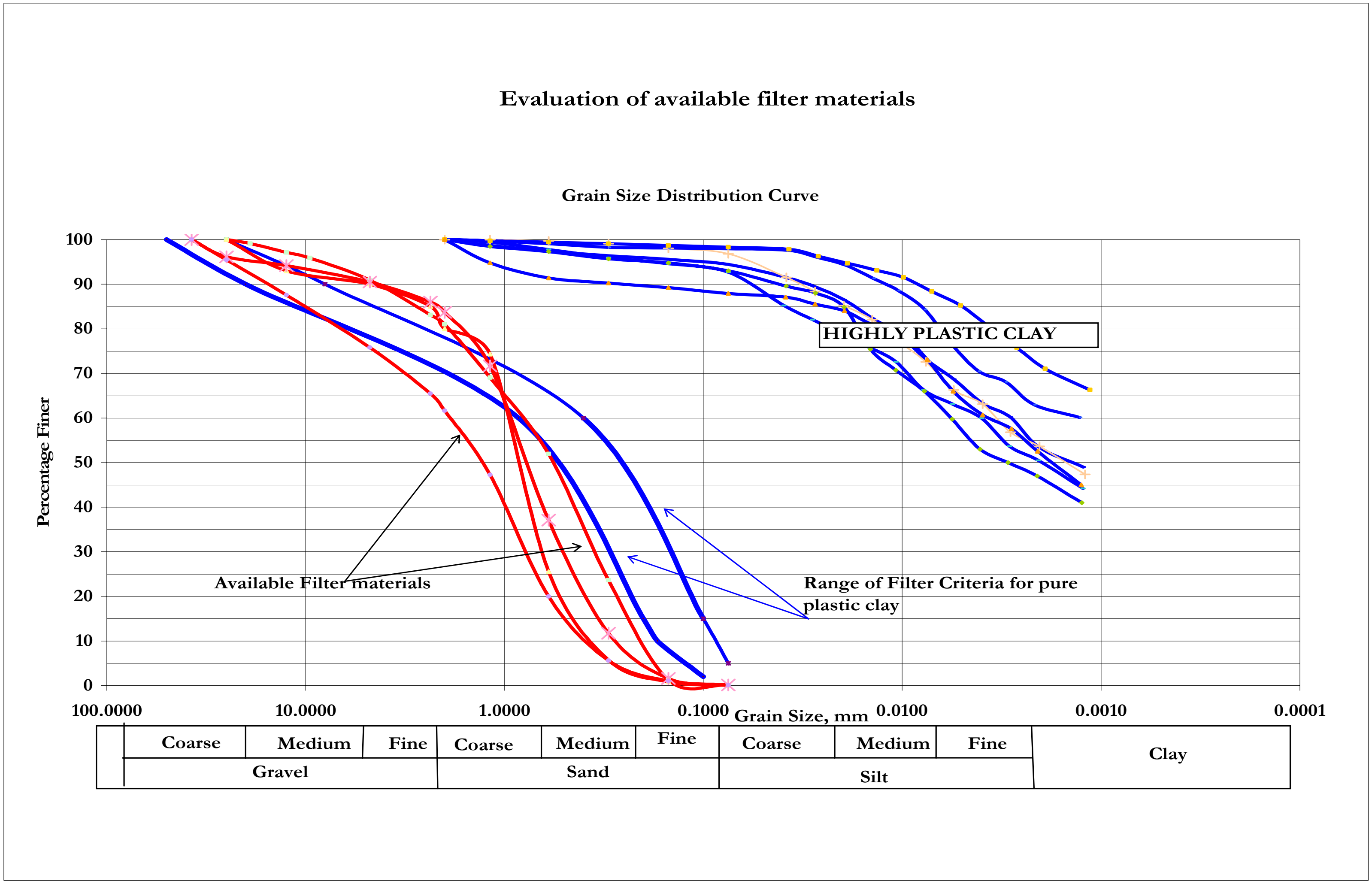


Fig 5.4: Evaluation of available filter materials for highly plastic clay

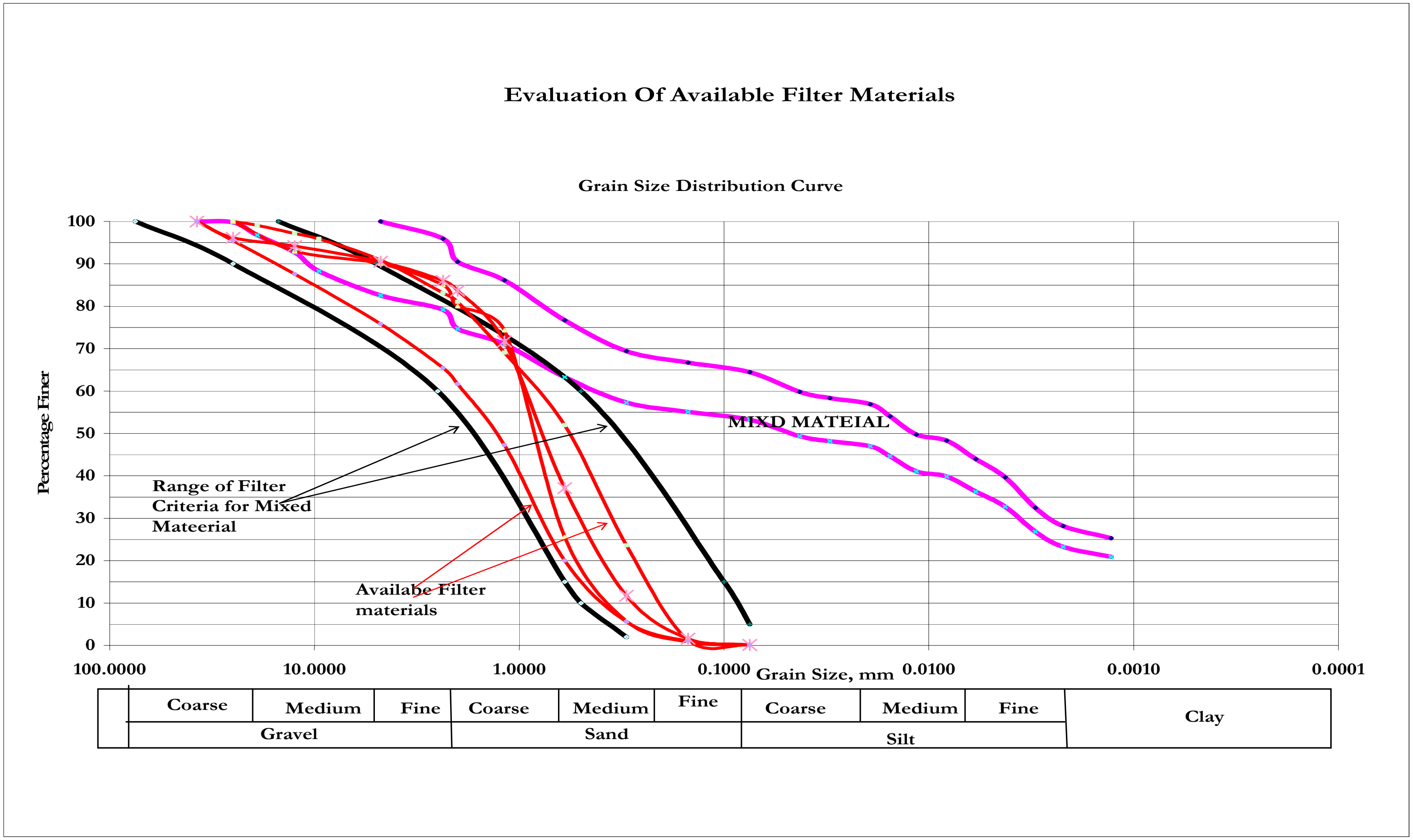


Fig 5.5: Evaluation of available filter materials for mixed clay

6 SUMMARY and CONCLUSIONS

CH soils are found in many parts of the country. Reports of geotechnical investigations obtained from several dam projects indicate that these soils are the predominantly available construction materials for the impervious core. However, several problems are associated with CH soils when used as impervious core of dams.

In this thesis, a study had been conducted on the effects of blending the CH soils with naturally available granular materials using several laboratory tests. The test results clearly revealed that blending with granular soils significantly improves the physical and mechanical behaviours of the CH soils.

For the impervious materials to be used in the clay core of embankment dams, limits of maximum dry unit weight, optimum water content, specific gravity, liquid limit and plasticity index have been given as: g_{dmax}.>1.6g/cm3, w_{opt}=15-20%,Gs>2.6, LL=40-50% and Ip=14-20% (*After Yilmaz and Karacan,1996)*.

When available plastic clays (CH) were evaluated according to the above proposed values, all parameters do not satisfy the requirements except the specific gravity Gs. Mixed clays with blending ratios ranging from 10/90 to 30/70 also failed to satisfy some of the requirements.

From the stand point of permeability, the optimum mixture percentage in which neither the material becomes too permeable nor remains too soft, was found to be 40/60. The mixed clay with blending ratio 50/50 also satisfied all requirements but its production would be more costly (hauling of more sandy gravel material) than the mixed clay with the blending ratio of 40/60. Besides according to Wagner [13] the mixed clay with a ratio of 50/50 – which is classified as SM – is less desirable to be used as impervious core than the 40/60 ratio. The mixed clay with 40/60 ratio is found to be able to do all duties expected for the core of the earth dams in a more suitable way than the highly plastic clay cores.

Based on the results of this study (conducted for 40/60 mixed material and highly plastic clay), the following conclusions are drawn:

I. The 40/60 mixed clay showed **48.91%** reduction of Ip, **20.15%** improvements in maximum dry density, **48.25%** reduction in optimum water content, **21.21%** reduction in compression index, and **25%** reduction in recompression index.

II. Mixing of gravelly sand to highly plastic clay reduced the swelling potential behavior of the material.

III. The compressibility behavior of highly plastic clay was improved when it is mixed with gravelly sand.

IV. The 40/60 mixed clay showed stronger and stiffer behaviors than the highly plastic clay.

V. Mixing of 40% sandy gravel to 60% highly plastic clay increased the freedom of selection and/or production ranges of the filter materials.

VI. Relative desirability rating for core was improved form **9** (very low level of desirability for CH soils) to **3** (good level of desirability for mixed CL soils) according to the **Engineering Use Chart (After Wagner, 1957).**

VII. The ease of moisture-density control (Workability) was improved from very poor workability to good workability conditions **(After Wagner, 1957).**

7 Appendices

Appendix - A

Criteria's for filter material determinations

Table A-1: Base soil categories

Base soil category	% finer than 0.0075mm (after regarding where applicable)	Base soil Description
1	>85	Fine Silts and Clays
2A	35 - 85	Silty and Clayey sand; Sandy Clay; and Silt ,Sand, Gravel mixes
4A	15 – 35	Silty and Clayey Sands and Gravels
3	<15	Sand and Gravels

Table A-2: Filtering Criteria for critical filters- $D15_F$

Base soil Category	Filtering Criteria
1	< 9* D_{85B} but not less than 0.2mm
2A	< 0.7mm
3	< 4* $D_{85B}$of base soil after regarding

Table A-3: Permeability Criteria

Base soil Category	Criteria
All categories	Minimum D_{85F}> 4* D_{15B} of the base soil before regarding but not less than 0.1mm.

Table A-4: Other Filter Criteria

Design element	Criteria
To prevent gap-graded filters Filter band limits	The width of the designed filter band should be such that the ratio of the maximum diameter to the minimum diameter at any given percent passing value < 60%is < 5. Coarse and fine limits of a filter band should each have a coefficient of uniformity of 6 or less.

Table A-5: Segregation Criteria

Base soil Category	If D_{10F} (mm) is :	Then maximum D_{90F} (mm) is:
All categories	<0.5	20
	0.5-1.0	25
	1.0 -2.0	30
	2.0 – 5.0	40
	5.0 – 10	50
	>10	60

APPENDIX - B

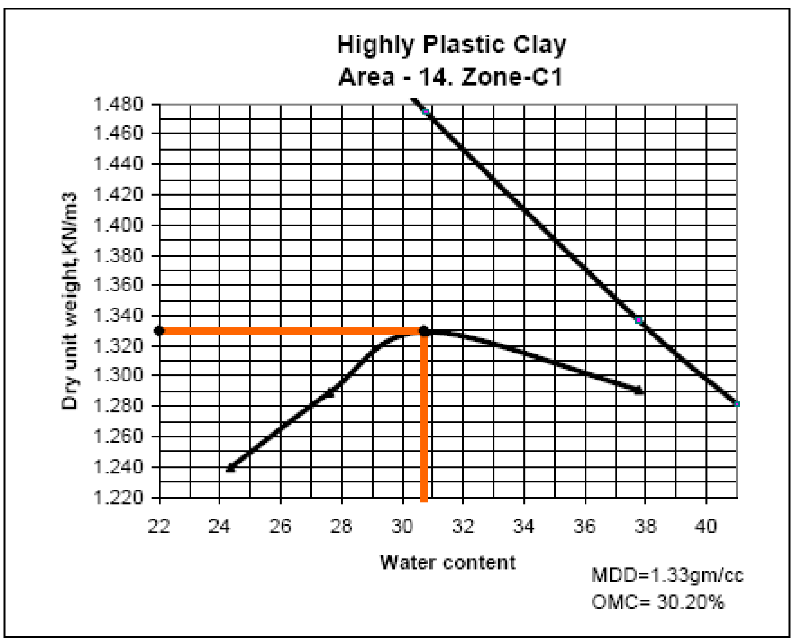
MDD & OMC COMPUTATIONS FOR HIGHLY PLASTIC CLAY

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit : Area -14 , Zone-C1
Depth : Stock Pile

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4
Water in cc	300	450	600	750
Wt.of mould + Wet sample(g)	5261	5359	5447	5485
Wt.of mould (g)	3806	3806	3806	3806
Wt.of wet soil(g)	1455	1553	1641	1679
Volume of mould cm3	944	944	944	944
Wet Density mg /cm3	1.54	1.65	1.74	1.78
Moisture content				
Tin No.	35	153	27	162
Wet soil + tin (g)	79.60	67.70	85.60	71.50
Dry soil + tin (g)	68.4	57.9	70.8	57.9
Wt of tin (g)	22.4	22.4	22.7	21.9
Wt of Water (g)	11.2	9.8	14.8	13.6
Wt of Dry soil (g)	46	35.5	48.1	36
Moisture content %	24.35	27.61	30.77	37.78
Dry Density mg /cm3	1.240	1.289	1.329	1.291
Zero Air Voids (100% Saturation)	1.63	1.55	1.47	1.34



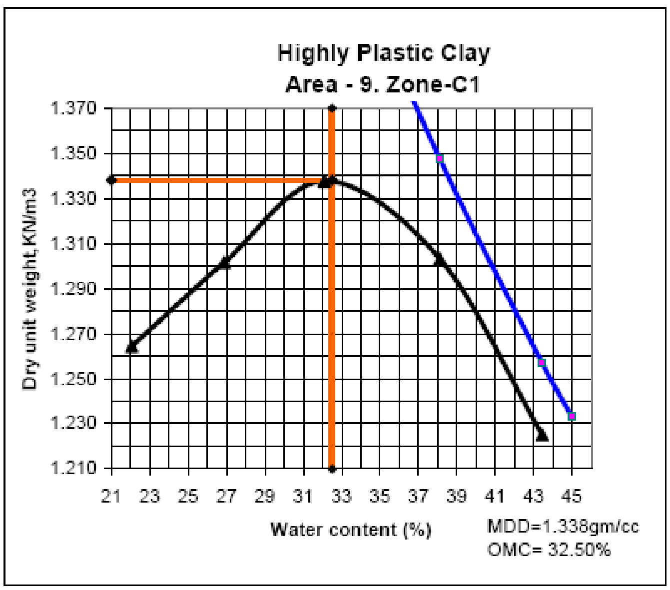
MDD : 1.33 gm/cc
OMC : 30.20 %

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit : Area -9, Zone-C1
Depth : Stock Pile

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4	5
Water in cc	300	400	500	600	700
Wt.of mould + Wet sample(g)	5263	5365	5474	5505	5465
Wt.of mould (g)	3806	3806	3806	3806	3806
Wt.of wet soil(g)	1457	1559	1668	1699	1659
Volume of mould cm3	944	944	944	944	944
Wet Density mg /cm3	1.54	1.65	1.77	1.80	1.76
Moisture content					
Tin No.	48	15	144	70	32
Wet soil + tin (g)	72.40	72.50	68.30	61.90	74.10
Dry soil + tin (g)	63.4	61.8	57.1	51	58.5
Wt of tin (g)	22.6	22	22.2	22.4	22.6
Wt of Water (g)	9	10.7	11.2	10.9	15.6
Wt of Dry soil (g)	40.8	39.8	34.9	28.6	35.9
Moisture content %	22.06	26.88	32.09	38.11	43.45
Dry Density mg /cm3	1.264	1.302	1.338	1.303	1.225
Zero Air Voids 100%	1.72	1.59	1.47	1.35	1.26



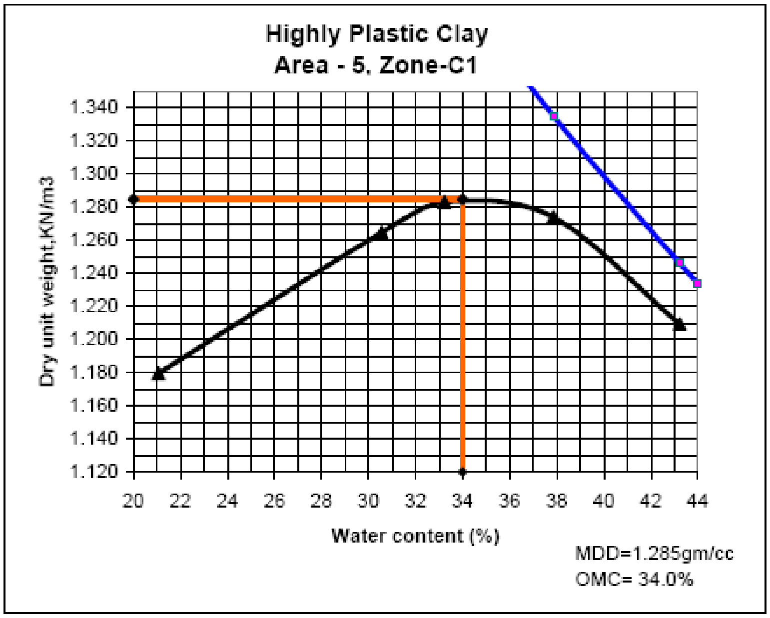
MDD : 1.338 gm/cc
OMC : 32.5 %

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit : Area -5, Zone-C1
Depth : Stock Pile

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4	5
Water in cc	300	400	500	600	700
Wt.of mould + Wet sample(g)	5154	5365	5420	5464	5441
Wt.of mould (g)	3806	3806	3806	3806	3806
Wt.of wet soil(g)	1348	1559	1614	1658	1635
Volume of mould cm3	944	944	944	944	944
Wet Density mg /cm3	1.43	1.65	1.71	1.76	1.73
Moisture content					
Tin No.	142	169	166	56	37
Wet soil + tin (g)	72.50	55.20	65.10	60.00	67.60
Dry soil + tin (g)	63.8	47.5	54.6	49.4	53.9
Wt of tin (g)	22.5	22.3	23	21.4	22.2
Wt of Water (g)	8.7	7.7	10.5	10.6	13.7
Wt of Dry soil (g)	41.3	25.2	31.6	28	31.7
Moisture content %	21.07	30.56	33.23	37.86	43.22
Dry Density mg /cm3	1.180	1.265	1.283	1.274	1.209
Zero Air Voids 100%	1.72	1.48	1.42	1.34	1.25



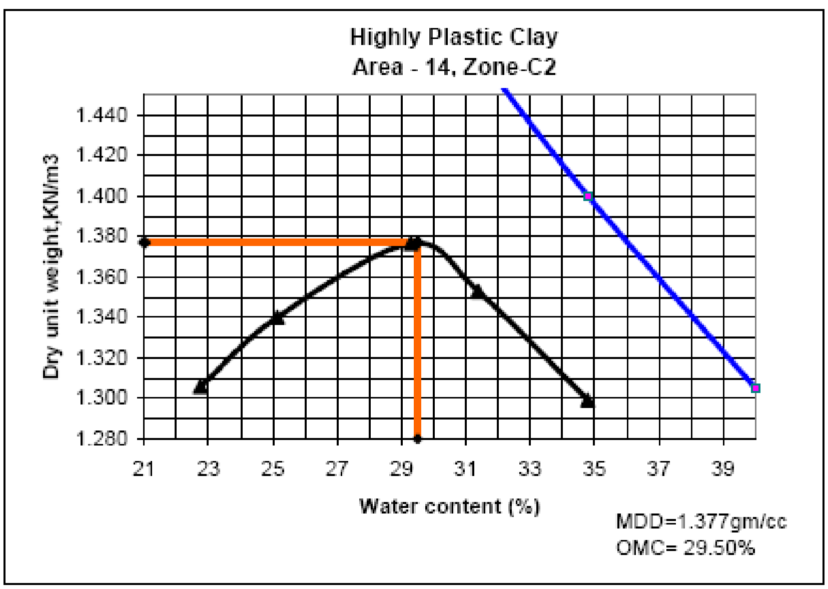
MDD : 1.285 gm/cc
OMC :34.0%

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit : Area -14 , Zone-C2
Depth : Stock Pile

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4	5
Water in cc	300	360	420	480	540
Wt.of mould + Wet sample(g)	5319	5389	5486	5484	5459
Wt.of mould (g)	3806	3806	3806	3806	3806
Wt.of wet soil(g)	1513	1583	1680	1678	1653
Volume of mould cm3	944	944	944	944	944
Wet Density mg /cm3	1.60	1.68	1.78	1.78	1.75
Moisture content					
Tin No.	35	120	44	32	121
Wet soil + tin (g)	154.83	138.65	147.88	150.81	179.48
Dry soil + tin (g)	130.25	115.18	119.59	119.9	138.89
Wt of tin (g)	22.2	21.8	23	21.4	22.2
Wt of Water (g)	24.58	23.47	28.29	30.91	40.59
Wt of Dry soil (g)	108.05	93.38	96.59	98.5	116.69
Moisture content %	22.75	25.13	29.29	31.38	34.78
Dry Density mg /cm3	1.306	1.340	1.377	1.353	1.299
Zero Air Voids 100%	1.68	1.62	1.52	1.47	1.40



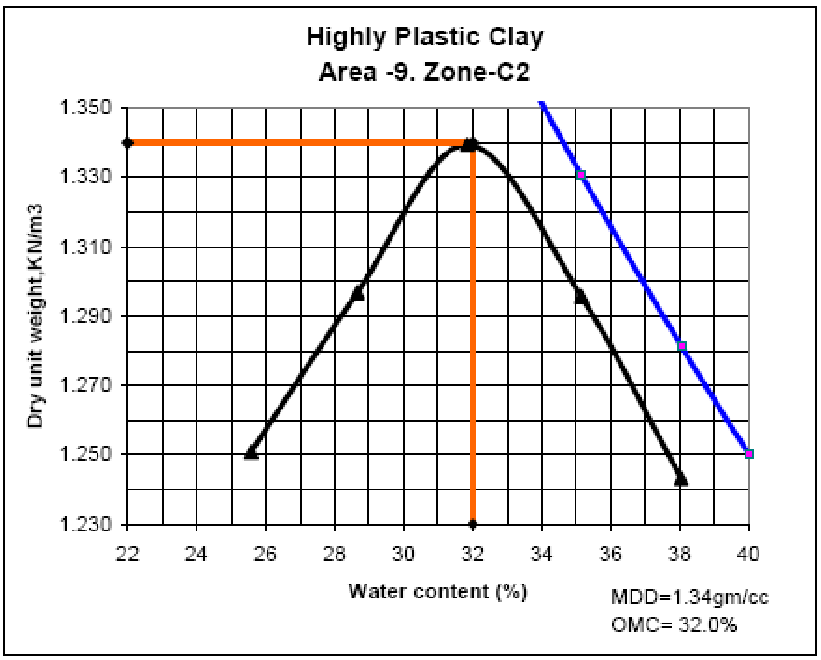
MDD : 1.377 gm/cc
OMC : 29.50 %

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit : Area -9, Zone-C2
Depth : Stock Pile

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4	5
Water in cc	300	360	420	480	540
Wt.of mould + Wet sample(g)	5289	5381	5473	5459	5426
Wt.of mould (g)	3806	3806	3806	3806	3806
Wt.of wet soil(g)	1483	1575	1667	1653	1620
Volume of mould cm3	944	944	944	944	944
Wet Density mg /cm3	1.57	1.67	1.77	1.75	1.72
Moisture content					
Tin No.	160	170	180	190	200
Wet soil + tin (g)	115.17	114.07	107.04	117.41	129.54
Dry soil + tin (g)	96.12	93.54	86.41	92.54	99.89
Wt of tin (g)	21.67	21.9	21.62	21.78	21.95
Wt of Water (g)	19.05	20.53	20.63	24.87	29.65
Wt of Dry soil (g)	74.45	71.64	64.79	70.76	77.94
Moisture content %	25.59	28.66	31.84	35.15	38.04
Dry Density mg /cm3	1.251	1.297	1.339	1.296	1.243
Zero Air Voids 100%	1.52	1.46	1.39	1.33	1.28



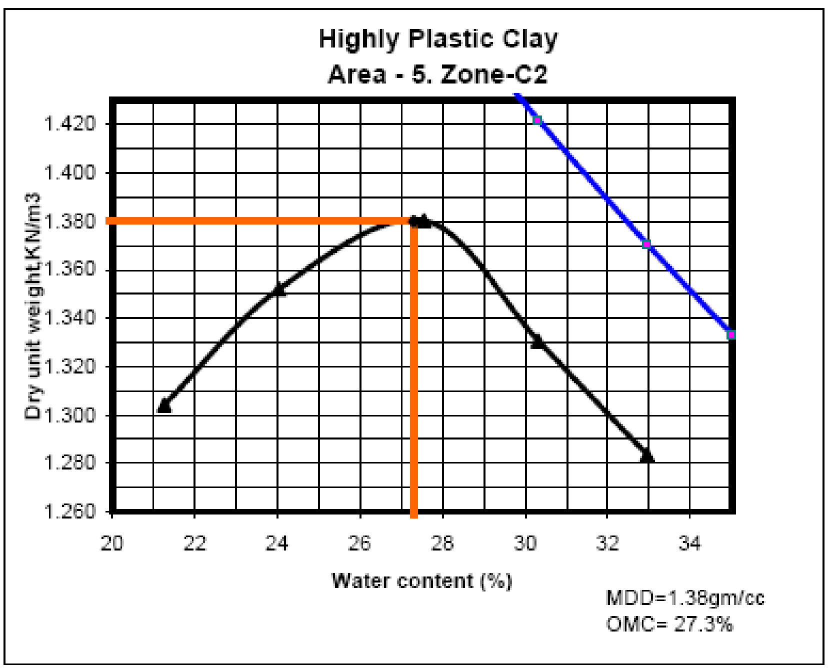
MDD : 1.34 gm/cc
OMC : 32.0 %

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit : Area -5 , Zone-C2
Depth : Stock Pile

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4	5
Water in cc	300	450	600	750	900
Wt.of mould + Wet sample(g)	5299	5389	5468	5443	5417
Wt.of mould (g)	3806	3806	3806	3806	3806
Wt.of wet soil(g)	1493	1583	1662	1637	1611
Volume of mould cm3	944	944	944	944	944
Wet Density mg /cm3	1.58	1.68	1.76	1.73	1.71
Moisture content					
Tin No.	110	120	130	140	150
Wet soil + tin (g)	113.77	98.22	110.85	133.59	130.64
Dry soil + tin (g)	97.7	83.31	91.64	107.58	103.6
Wt of tin (g)	22.12	21.27	21.91	21.78	21.54
Wt of Water (g)	16.07	14.91	19.21	26.01	27.04
Wt of Dry soil (g)	75.58	62.04	69.73	85.8	82.06
Moisture content %	21.26	24.03	27.55	30.31	32.95
Dry Density mg /cm3	1.304	1.352	1.380	1.331	1.284
Zero Air Voids 100%	1.63	1.56	1.48	1.42	1.37



MDD : 1.38 gm/cc
OMC : 27.3 %

Appendix - C

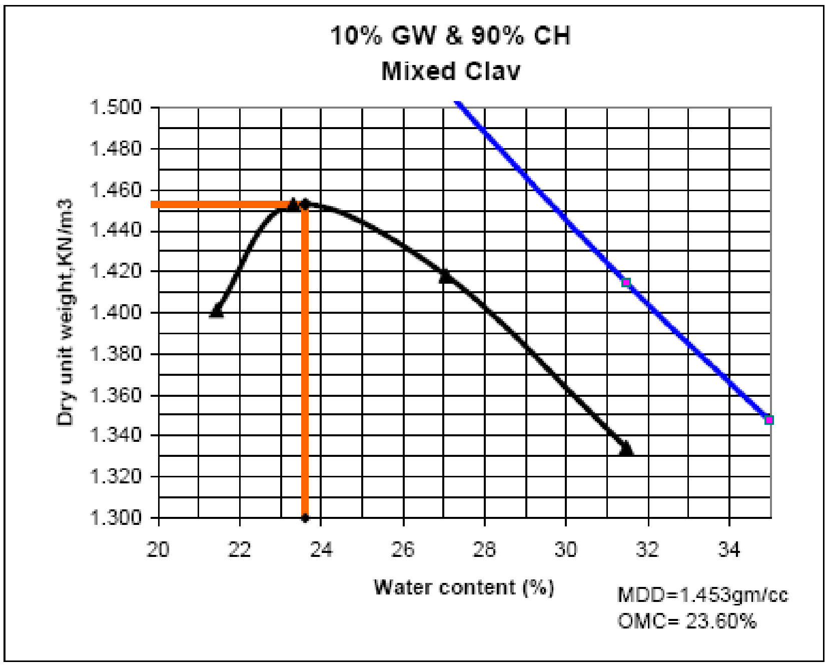
MDD & OMC COMPUTATIONS FOR MIXED CLAY

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit :
Depth : Mixed (10% Gravelly sand & 90% clay)

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4
Water in cc	300	360	420	480
Wt.of mould + Wet sample(g)	5412	5497	5507	5462
Wt.of mould (g)	3806	3806	3806	3806
Wt.of wet soil(g)	1606	1691	1701	1656
Volume of mould cm3	944	944	944	944
Wet Density mg /cm3	1.70	1.79	1.80	1.75
Moisture content				
Tin No.	16	52	34	120
Wet soil + tin (g)	134.93	121.37	143.12	172.40
Dry soil + tin (g)	115.13	102.48	117.26	136.3
Wt of tin (g)	22.72	21.43	21.67	21.6
Wt of Water (g)	19.8	18.89	25.86	36.1
Wt of Dry soil (g)	92.41	81.05	95.59	114.7
Moisture content %	21.43	23.31	27.05	31.47
Dry Density mg /cm3	1.401	1.453	1.418	1.334
Zero Air Voids 100%	1.65	1.60	1.51	1.41



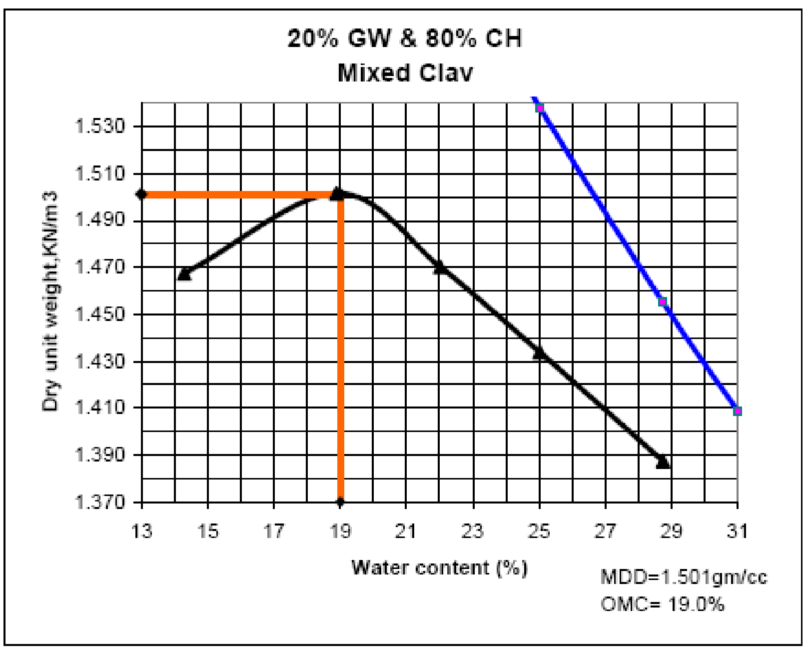
MDD : 1.453 gm/cc
OMC : 23.6 %

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit :
Depth : Mixed (20% Gravelly sand & 80% clay)

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4	5
Water in cc	240	300	360	420	480
Wt.of mould + Wet sample(g)	5389	5491	5534	5498	5492
Wt.of mould (g)	3806	3806	3806	3806	3806
Wt.of wet soil(g)	1583	1685	1728	1692	1686
Volume of mould cm3	944	944	944	944	944
Wet Density mg /cm3	1.68	1.78	1.83	1.79	1.79
Moisture content					
Tin No.	23	54	120	37	97
Wet soil + tin (g)	140.50	138.87	140.21	158.57	189.96
Dry soil + tin (g)	125.6	120.23	118.8	131.26	150.82
Wt of tin (g)	21.33	21.52	21.61	22.09	14.6
Wt of Water (g)	14.9	18.64	21.41	27.31	39.14
Wt of Dry soil (g)	104.27	98.71	97.19	109.17	136.22
Moisture content %	14.29	18.88	22.03	25.02	28.73
Dry Density mg /cm3	1.467	1.501	1.470	1.434	1.387
Zero Air Voids 100%	1.84	1.70	1.61	1.54	1.45



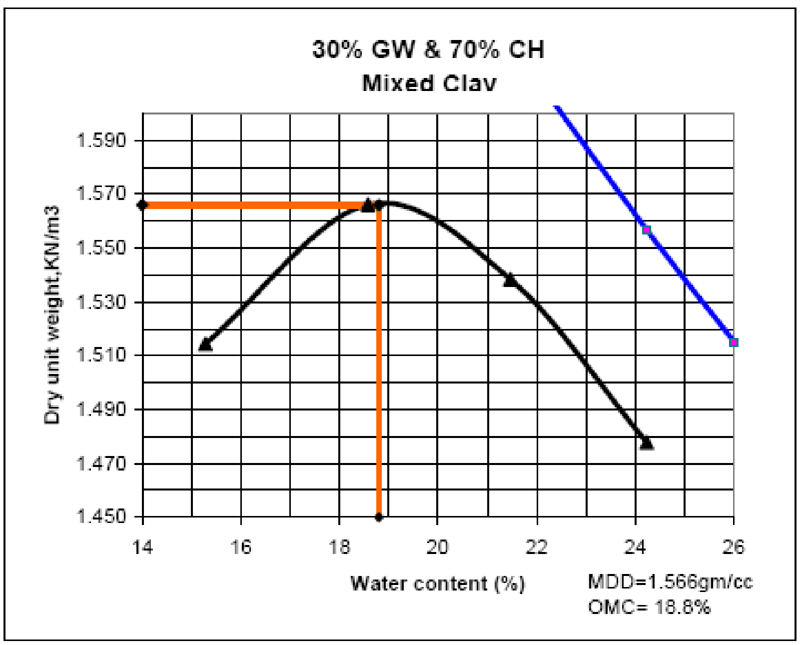
MDD : 1.501 gm/cc
OMC : 19.0 %

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit :
Depth : Mixed (30% Gravelly sand & 70% clay)

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4
Water in cc	240	300	360	420
Wt.of mould + Wet sample(g)	5454	5559	5570	5539
Wt.of mould (g)	3806	3806	3806	3806
Wt.of wet soil(g)	1648	1753	1764	1733
Volume of mould cm3	944	944	944	944
Wet Density mg /cm3	1.75	1.86	1.87	1.84
Moisture content				
Tin No.	32	46	89	123
Wet soil + tin (g)	113.11	139.97	130.10	163.50
Dry soil + tin (g)	100.95	121.41	110.91	135.8
Wt of tin (g)	21.37	21.5	21.52	21.49
Wt of Water (g)	12.16	18.56	19.19	27.7
Wt of Dry soil (g)	79.58	99.91	89.39	114.31
Moisture content %	15.28	18.58	21.47	24.23
Dry Density mg /cm3	1.514	1.566	1.538	1.478
Zero Air Voids 100%	1.81	1.71	1.63	1.56



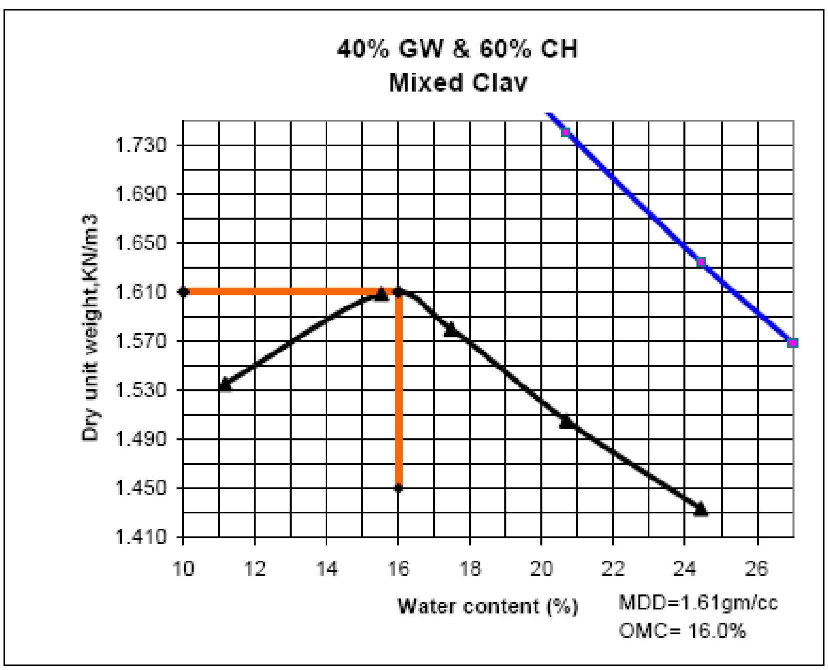
MDD : 1.566 gm/cc
OMC : 18.8 %

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit :
Depth : Mixed (40% Gravelly sand & 60% clay)

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4	5
Water in cc	240	300	360	420	480
Wt.of mould + Wet sample(g)	5417	5560	5558	5521	5490
Wt.of mould (g)	3806	3806	3806	3806	3806
Wt.of wet soil(g)	1611	1754	1752	1715	1684
Volume of mould cm3	944	944	944	944	944
Wet Density mg /cm3	1.71	1.86	1.86	1.82	1.78
Moisture content					
Tin No.	F	G	H	I	J
Wet soil + tin (g)	132.02	151.48	154.72	163.40	177.99
Dry soil + tin (g)	120.91	134	134.86	139.08	147.29
Wt of tin (g)	21.39	21.38	21.23	21.54	21.63
Wt of Water (g)	11.11	17.48	19.86	24.32	30.7
Wt of Dry soil (g)	99.52	112.62	113.63	117.54	125.66
Moisture content %	11.16	15.52	17.48	20.69	24.43
Dry Density mg /cm3	1.535	1.608	1.580	1.505	1.434
Zero Air Voids 100%	2.09	1.91	1.84	1.74	1.63



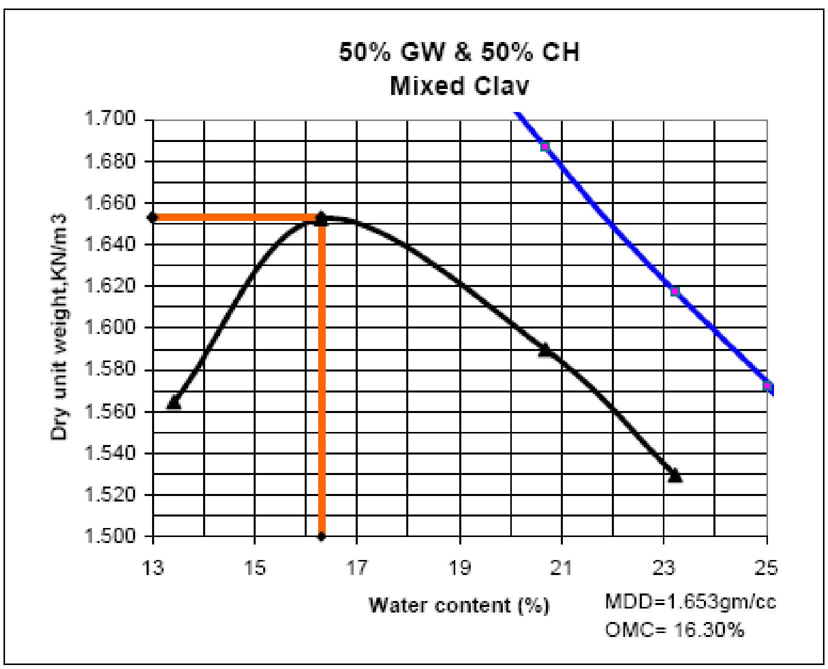
MDD : 1.61 gm/cc
OMC : 16 %

Procter Test

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
Test Pit :
Depth : Mixed (50% Gravelly sand & 50% clay)

Sample type : Disturbed
Test type : Standard Proctor

Lab.test No.	1	2	3	4	5
Water in cc	240	300	360	420	480
Wt.of mould + Wet sample(g)	5481	5620	5617	5585	5316
Wt.of mould (g)	3806	3806	3806	3806	3806
Wt.of wet soil(g)	1675	1814	1811	1779	1510
Volume of mould cm3	944	944	944	944	944
Wet Density mg /cm3	1.77	1.92	1.92	1.88	1.60
Moisture content					
Tin No.	1	3	4	5	2
Wet soil + tin (g)	120.97	140.37	161.38	148.05	162.71
Dry soil + tin (g)	109.16	123.71	137.34	124.18	130.48
Wt of tin (g)	21.12	21.44	21.09	21.37	21.12
Wt of Water (g)	11.81	16.66	24.04	23.87	32.23
Wt of Dry soil (g)	88.04	102.27	116.25	102.81	109.36
Moisture content %	13.41	16.29	20.68	23.22	29.47
Dry Density mg /cm3	1.564	1.652	1.590	1.529	
Zero Air Voids 100%	1.92	1.82	1.69	1.62	1.47



MDD : 1.653gm/cc
OMC : 16.3%

Appendix- D

LIQUID LIMIT & PLASTIC LIMIT COMPUTATIONS FOR HIGHLY PLASTIC CLAY

LIQUID AND PLASTIC LIMIT
DETERMINATIONS

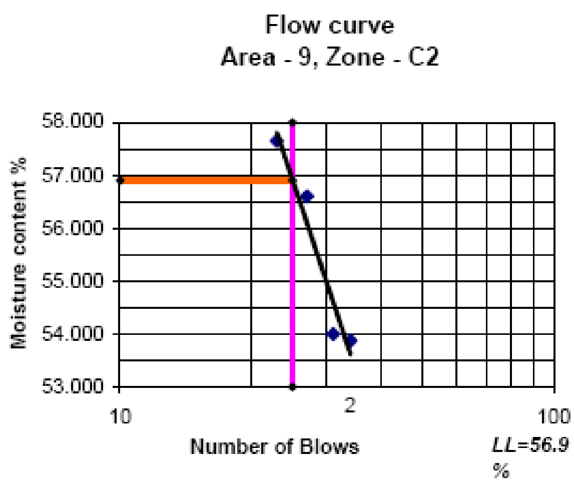
Project : Tendaho Dam & Irrigation Project
Location : Tendaho
T.Pit No : Area-9,Zone-C2
Depth : Stock Pile

Sam Type : Disturbed
Test Type : Liquid & Plastic Limit

DETERMINATIONS
DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	72	D36	C2	A14
No. of Blows	23	27	31	34
Wt.of sample + Tare wet	49.769	64.703	60.295	55.503
Wt.of sample + Tare dry	37.294	46.938	44.654	41.543
Wt.of water	12.475	17.765	15.641	13.960
Tare	15.656	15.551	15.690	15.630
wt.of dry soil	21.638	31.387	28.964	25.913
Water content %	57.653	56.600	54.002	53.873

Type of test	PL	PL	
Conteiner No.	63	14	
Wt.of sample + Tare wet	20.489	20.533	
Wt.of sample + Tare dry	19.647	19.396	
Wt.of water	0.842	1.137	
Tare	15.607	15.631	
wt.of dry soil	4.040	3.765	
Water content %	20.842	30.199	25.520



L. Limit	56.90%
P. limit	25.52%
P. Index	31.38%

LIQUID AND PLASTIC LIMIT DETERMINATIONS

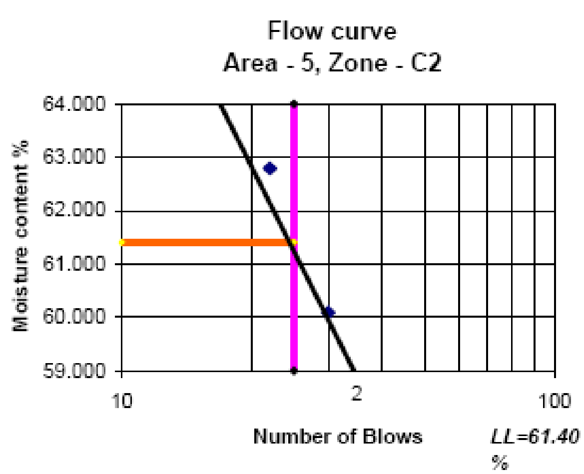
Project : Tendaho Dam & Irrigation Project
Location : Tendaho
T.Pit No : Area-5,Zone-C2
Depth : Stock Pile

Sam Type : Disturbed
Test Type : Liquid & Plastic Limit

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	30	50	38	157
No. of Blows	38	30	22	14
Wt.of sample + Tare wet	52.560	58.000	57.3	53.700
Wt.of sample + Tare dry	41.500	44.900	43.8	41.300
Wt.of water	11.060	13.100	13.500	12.400
Tare	22.400	23.100	22.3	22.200
wt.of dry soil	19.100	21.800	21.500	19.100
Water content %	57.906	60.092	62.791	64.921

Type of test	PL	PL	
Conteiner No.	135	144	
Wt.of sample + Tare wet	29.200	28.400	
Wt.of sample + Tare dry	27.600	26.900	
Wt.of water	1.600	1.500	
Tare	22.300	22.200	
wt.of dry soil	5.300	4.700	
Water content %	30.189	31.915	31.052



L. Limit	61.40%
P. limit	31.05%
P. Index	30.35%

LIQUID AND PLASTIC LIMIT DETERMINATIONS

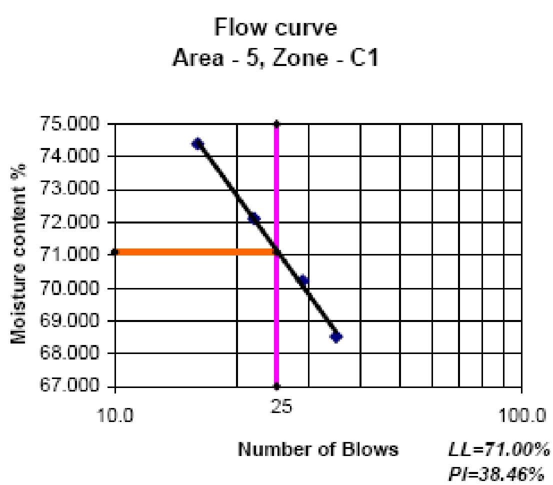
Project : Tendaho Dam & Irrigation Project
Location : Tendaho
T.Pit No : Area-5,Zone-C1
Depth : Stock Pile

Sam Type : Disturbed
Test Type : Liquid & Plastic Limit

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	170	144	37	151
No. of Blows	35.0	29.0	22.0	16.0
Wt.of sample + Tare wet	40.000	52.500	50.600	44.200
Wt.of sample + Tare dry	32.600	40.000	38.700	34.900
Wt.of water	7.400	12.500	11.900	9.300
Tare	21.800	22.200	22.200	22.400
wt.of dry soil	10.800	17.800	16.500	12.500
Water content %	68.519	70.225	72.121	74.400

Type of test	PL	PL	
Conteiner No.	165	171	
Wt.of sample + Tare wet	29.800	29.700	
Wt.of sample + Tare dry	27.700	27.700	
Wt.of water	2.100	2.000	
Tare	21.400	21.400	
wt.of dry soil	6.300	6.300	
Water content %	33.333	31.746	32.540



L. Limit	71.00%
P. limit	32.54%
P. Index	38.46%

LIQUID AND PLASTIC LIMIT DETERMINATIONS

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
T.Pit No : Area-9,Zone-C1
Depth : Stock Pile

Sam Type : Disturbed
Test Type : Liquid & Plastic Limit

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	39	19	38	36
No. of Blows	36.0	30.0	22.0	14.0
Wt.of sample + Tare wet	46.750	45.700	41.990	39.800
Wt.of sample + Tare dry	36.400	35.400	33.300	31.700
Wt.of water	10.350	10.300	8.690	8.100
Tare	22.800	22.200	22.300	21.600
wt.of dry soil	13.600	13.200	11.000	10.100
Water content %	76.103	78.030	79.000	80.198

Type of test	PL	PL	
Conteiner No.	49	171	
Wt.of sample + Tare wet	32.000	32.500	
Wt.of sample + Tare dry	29.300	30.000	
Wt.of water	2.700	2.500	
Tare	21.900	22.300	
wt.of dry soil	7.400	7.700	
Water content %	36.486	32.468	34.477

Flow curve
Area - 9, Zone - C1

L. Limit	78.20%
P. limit	34.45%
P. Index	43.75%

LIQUID AND PLASTIC LIMIT DETERMINATIONS

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
T.Pit No : Area-9,Zone-C1
Depth : Stock Pile

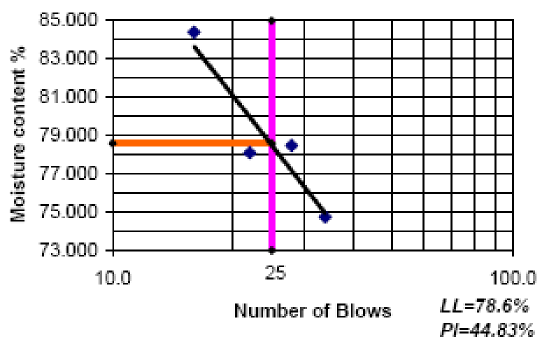
Sam Type : Disturbed
Test Type : Liquid & Plastic Limit

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	158	165	155	190
No. of Blows	34.0	28.0	22.0	16.0
Wt.of sample + Tare wet	39.800	40.070	41.100	44.980
Wt.of sample + Tare dry	32.400	32.300	32.900	34.600
Wt.of water	7.400	7.770	8.200	10.380
Tare	22.500	22.400	22.400	22.300
wt.of dry soil	9.900	9.900	10.500	12.300
Water content %	74.747	78.485	78.095	84.390

Type of test	PL	PL	
Conteiner No.	154	170	
Wt.of sample + Tare wet	29.450	30.100	
Wt.of sample + Tare dry	27.500	28.100	
Wt.of water	1.950	2.000	
Tare	21.800	22.100	
wt.of dry soil	5.700	6.000	
Water content %	34.211	33.333	33.772

Flow curve
Area - 14, Zone - C1



L. Limit	78.60%
P. limit	33.77%
P. Index	44.83%

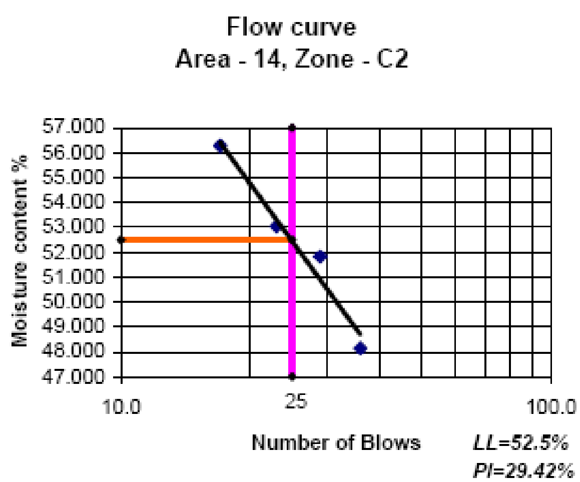
Location : Tendaho
T.Pit No : Area-14,Zone-C2
Depth : Stock Pile

Test Type : Liquid & Plastic Limit

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	167	44	27	39
No. of Blows	36.0	29.0	23.0	17.0
Wt.of sample + Tare wet	46.800	51.700	47.900	46.300
Wt.of sample + Tare dry	39.000	41.800	39.200	37.800
Wt.of water	7.800	9.900	8.700	8.500
Tare	22.800	22.700	22.800	22.700
wt.of dry soil	16.200	19.100	16.400	15.100
Water content %	48.148	51.832	53.049	56.291

Type of test	PL	PL	
Conteiner No.	134	32	
Wt.of sample + Tare wet	31.800	31.800	
Wt.of sample + Tare dry	30.000	30.000	
Wt.of water	1.800	1.800	
Tare	22.200	22.200	
wt.of dry soil	7.800	7.800	
Water content %	23.077	23.077	23.077



L. Limit	52.50%
P. limit	23.08%
P. Index	29.42%

Appendix- E

LIQUID LIMIT & PLASTIC LIMIT COMPUTATIONS FOR MIXED CLAY

LIQUID AND PLASTIC LIMIT
DETERMINATIONS

Project : Tendaho Dam & Irrigation Project
Location : Tendaho
T.Pit No :
Depth : Mixed (10% Gravelly Sand & 90% Clay)

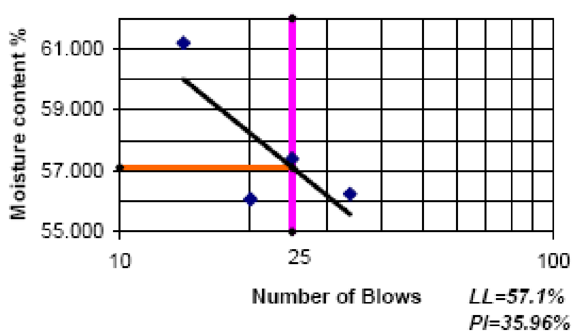
Sam Type : Disturbed
Test Type : Liquid & Plastic Limit

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	56	190	48	155
No. of Blows	34	25	20	14
Wt.of sample + Tare wet	53.900	54.250	51.81	50.900
Wt.of sample + Tare dry	42.200	42.600	41.1	40.080
Wt.of water	11.700	11.650	10.710	10.820
Tare	21.400	22.300	22	22.400
wt.of dry soil	20.800	20.300	19.100	17.680
Water content %	56.250	57.389	56.073	61.199

Type of test	PL	PL	
Conteiner No.	5	4	
Wt.of sample + Tare wet	34.440	33.510	
Wt.of sample + Tare dry	33.200	32.300	
Wt.of water	1.240	1.210	
Tare	27.200	26.700	
wt.of dry soil	6.000	5.600	
Water content %	20.667	21.607	21.137

Flow curve
Mixed Clay
(10%GW &90%CH)



L. Limit	57.10%
P. limit	21.14%
P. Index	35.96%

LIQUID AND PLASTIC LIMIT DETERMINATIONS

Project : Tendaho Dam & Irrigation Project

Location : Tendaho

T.Pit No :

Depth : Mixed (20% Gravelly Sand & 80% Clay)

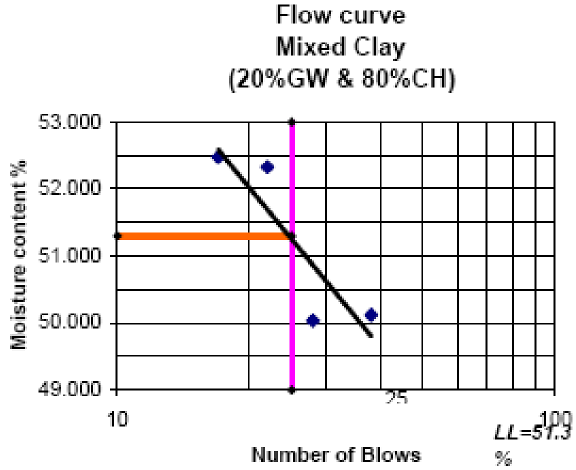
Sam Type : Disturbed

Test Type : Liquid & Plastic Lin

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	105	107	108	AE
No. of Blows	38	28	22	17
Wt.of sample + Tare wet	29.000	33.100	34.31	35.310
Wt.of sample + Tare dry	22.520	25.320	25.88	26.400
Wt.of water	6.480	7.780	8.430	8.910
Tare	9.590	9.770	9.77	9.420
wt.of dry soil	12.930	15.550	16.110	16.980
Water content %	50.116	50.032	52.328	52.473

Type of test	PL	PL	
Conteiner No.	C-1	C-2	
Wt.of sample + Tare wet	15.200	15.100	
Wt.of sample + Tare dry	14.200	13.600	
Wt.of water	1.000	1.500	
Tare	9.120	9.190	
wt.of dry soil	5.080	4.410	
Water content %	19.685	34.014	26.849



L. Limit	51.30%
P. limit	26.85%
P. Index	24.45%

LIQUID AND PLASTIC LIMIT

DETERMINATIONS

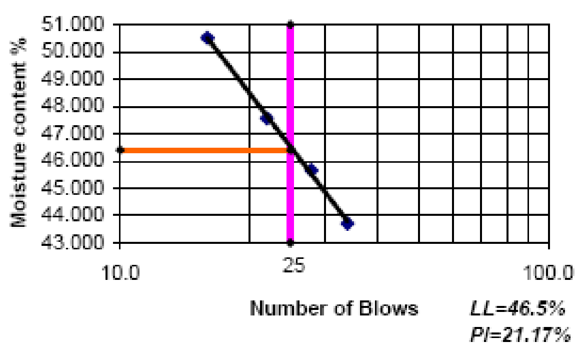
Project : Tendaho Dam & Irrigation Project Sam Type : Disturbed
Location : Tendaho Test Type : Liquid & Plastic Limit
T.Pit No :
Depth : Mixed (30% Gravelly Sand & 70% Clay)

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	165	169	27	28
No. of Blows	34.0	28.0	22.0	16.0
Wt.of sample + Tare wet	48.700	47.100	50.000	48.900
Wt.of sample + Tare dry	40.700	39.200	41.200	39.200
Wt.of water	8.000	7.900	8.800	9.700
Tare	22.400	21.900	22.700	20.000
wt.of dry soil	18.300	17.300	18.500	19.200
Water content %	43.716	45.665	47.568	50.521

Type of test	PL	PL	
Conteiner No.	38	190	
Wt.of sample + Tare wet	29.890	30.000	
Wt.of sample + Tare dry	28.400	28.400	
Wt.of water	1.490	1.600	
Tare	22.300	22.300	
wt.of dry soil	6.100	6.100	
Water content %	24.426	26.230	25.328

Flow curve
Mixed Clay
(30%GW & 70%CH)



L. Limit	46.50%
P. limit	25.33%
P. Index	21.17%

LIQUID AND PLASTIC LIMIT DETERMINATIONS

Project : Tendaho Dam & Irrigation Project

Sam Type : Disturbed

Location : Tendaho

Test Type : Liquid & Plastic Limit

T.Pit No :

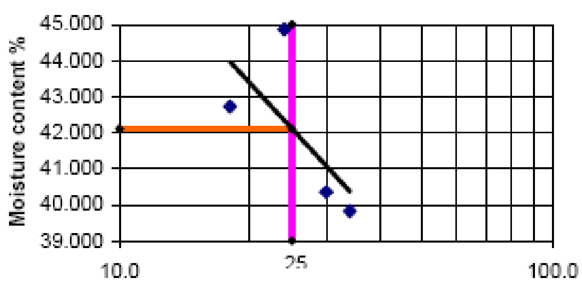
Depth : Mixed (40% Gravelly Sand & 60% Clay)

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	167	143	31	70
No. of Blows	34.0	30.0	24.0	18.0
Wt.of sample + Tare wet	54.300	54.500	53.800	56.100
Wt.of sample + Tare dry	45.300	45.300	44.200	46.100
Wt.of water	9.000	9.200	9.600	10.000
Tare	22.700	22.500	22.800	22.700
wt.of dry soil	22.600	22.800	21.400	23.400
Water content %	39.823	40.351	44.860	42.735

Type of test	PL	PL	
Conteiner No.	33	126	
Wt.of sample + Tare wet	33.100	32.300	
Wt.of sample + Tare dry	31.000	30.400	
Wt.of water	2.100	1.900	
Tare	22.200	22.200	
wt.of dry soil	8.800	8.200	
Water content %	23.864	23.171	23.517

Flow curve
Mixed Clay
(40%GW & 60%CH)



LL=42.1%
PI=18.58%

L. Limit	42.10%
P. limit	23.52%
P. Index	18.58%

LIQUID AND PLASTIC LIMIT

DETERMINATIONS

Project : Tendaho Dam & Irrigation Project

Location : Tendaho

T.Pit No :

Depth : Mixed (50% Gravelly Sand & 50% Clay)

Sam Type : Disturbed

Test Type : Liquid & Plastic Limit

DATA AND COMPUTATION SHEET

Type of test	LL	LL	LL	LL
Conteiner No.	126	152	158	33
No. of Blows	33.0	28.0	23.0	15.0
Wt.of sample + Tare wet	52.300	52.100	49.100	47.900
Wt.of sample + Tare dry	44.000	43.700	41.200	40.100
Wt.of water	8.300	8.400	7.900	7.800
Tare	22.200	22.700	22.500	22.200
wt.of dry soil	21.800	21.000	18.700	17.900
Water content %	38.073	40.000	42.246	43.575

Type of test	PL	PL	
Conteiner No.	172	143	
Wt.of sample + Tare wet	32.000	32.990	
Wt.of sample + Tare dry	30.600	30.600	
Wt.of water	1.400	2.390	
Tare	22.500	22.500	
wt.of dry soil	8.100	8.100	
Water content %	17.284	29.506	23.395

Flow curve
Mixed Clay
(50%GW & 50%CH)

LL=40.60%
PI=17.2%

L. Limit	40.60%
P. limit	26.40%
P. Index	14.20%

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Candidates Declaration

I hereby declare that the work which is being presented in this thesis entitles " **Appropriate solution for embankment dams to be constructed using highly plastic soils**" (the case of Tendaho Dam is original work of my own, has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged.

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Wuletaw Adane (Candidate) Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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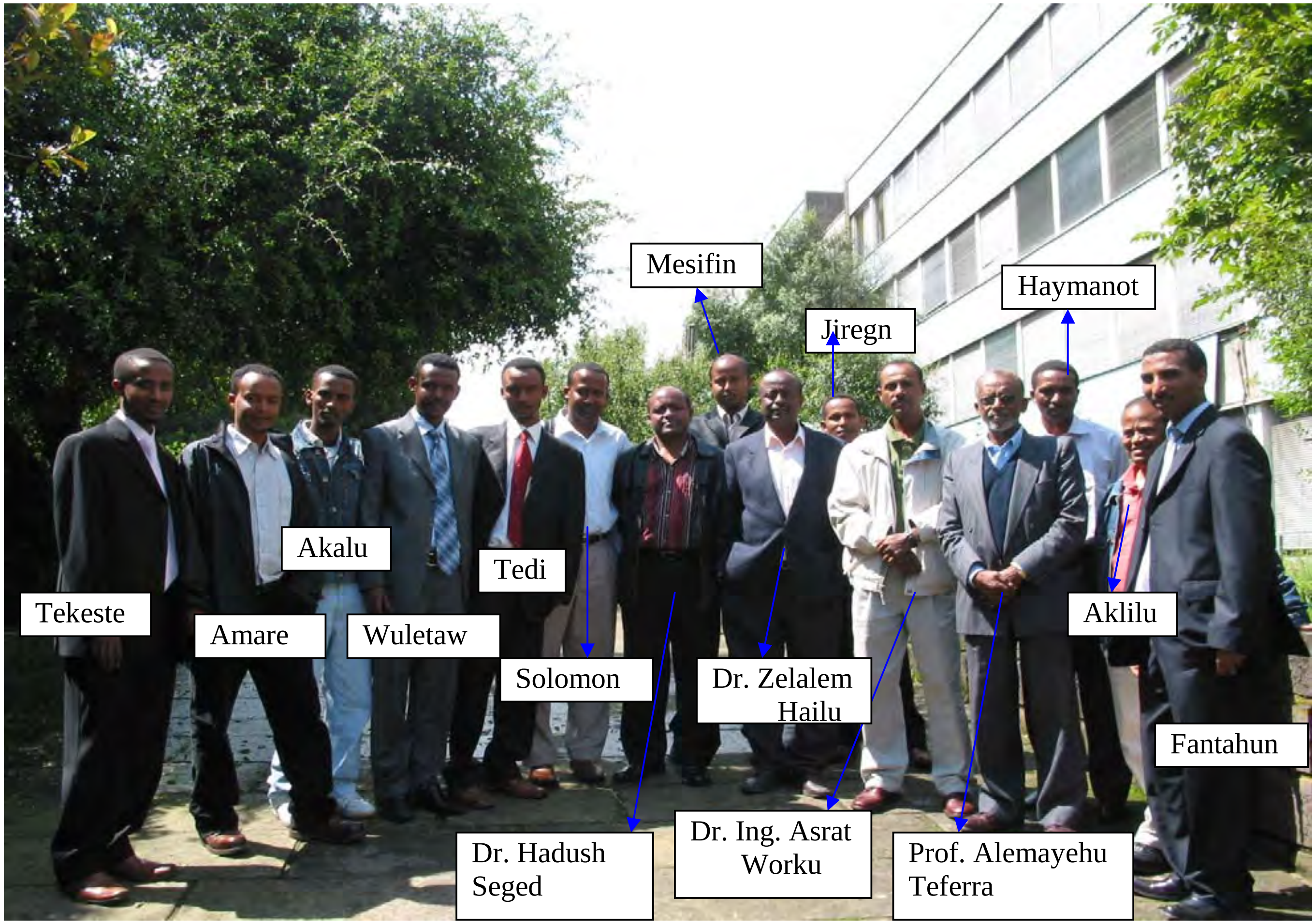
Dr. Hadush Seged (Thesis Advisor) Date



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