ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Investigation into the appropriate laboratory testing procedures for the determination of the index properties of the Lateritic Soils of Western Ethiopia

(Nedjo-Jarso-Begi Road area)

By

Wossen Million

November 2009

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A thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering

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DECLARATION

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Dr. Mesele Haile and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have also been duly acknowledged.

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Acknowledgements

I would like to express my sincere and deepest gratitude to my advisor Dr. Messele Haile for all his limitless efforts in guiding and supervising me throughout my research works and for providing me useful materials.

I express my sincere gratitude to Nedjo-Jarso-Begi road construction supervision consultant, Highway Engineers and Consultants/HEC/ plc, staffs for their contribution in facilitating all things and providing me necessary materials and vehicles during my site visit and samplings.

I am very grateful to AAU geotechnical laboratory workers, especially Ato Yonas Mekonen and Ato Demisew Melaku for their contribution in carrying out some of the laboratory tests.

Above all I am very thankful to Almighty God who is always with me throughout my difficulties. Finally I would like to express my deepest gratitude to my wife, Yodit Tadiwos; my friend, Shimelis G/Senbet and Highway Engineers and Consultants/HEC/ plc office, and all who contributed to this research work in one way or another.

Abstract

The appropriate laboratory testing procedures while carrying out index property tests of lateritic soils found in western Ethiopia (Nedjo, Jarso and Begi areas) have been investigated. Classification and composition of these soils have also been studied. The X-Ray Diffraction (XRD) analyses revealed that the soils in these areas are composed of minerals of Kaolinite and Smectite groups; such as Kaolinite, Quartz, Hematite, Vermiculite, Dickite, Borax, Illite, Nacrite. The X-Ray Fluorescent (XRF) analysis showed that there is a high concentration of sesquioxide minerals and there is no amorphous material present in the soils.

Comparison between the moisture contents determined using air drying (or alternatively 50^{o}C oven drying temperature) and that of 105^{o}C oven drying temperatures indicates that there is no significant amount of structural water; however, comparing to the non-lateritic soils from Addis Ababa, the western Ethiopia lateritic soils have some amount of structural water or water of hydration.

In the analysis of Atterberg Limits, in majority of the soils difference was observed between the Atterberg Limits obtained from test on a specimen mixed for 5min and that of 30min, this indicates that the cementation of the clay particles is to be disaggregated with higher mixing time.

Analysis of specific gravities of the soils using various pretreatment and testing procedures showed that, increase in drying temperature from its in situ condition to an air-dried or equivalent of 50^{o}C oven drying temperature and further to 105^{o}C oven drying temperature reduces specific gravity of the soils.

Analyses of the grain-size distributions (grading curves) with respect to the effects of different testing procedures (pre-test treatment methods), the effects of specific gravity variation within a sample, and the variation of sample location /depth/ and other physical properties indicated that the soils were not homogeneous within the laterite zone. The dry sample preparation and testing procedures tends to decrease the percentage of coarser particles as the coarser particles became highly fractured during the pulverization process. As a result these dry sieving techniques were found to be inappropriate. The analyses of the grading curves using mass proportion and the modified grading curve using volume proportion, which uses separate specific gravity, showed that the two grading curves are nearly the same; hence, the need of modifying the grading curves by volume proportion is not as such important especially when wet sieving method is used. Moreover, the analysis of grading curves with respect to sampling depth showed that, generally, the soils become coarser as the sampling depth increases. This confirms that the degree of weathering decreases with depth.

Soil classification using Unified Soil Classification System (USCS), AASHTO Classification System, Wesley’s Classification Method (classification using mineralogical composition) and soil grouping using genetic basis and soil forming factors were analyzed. According to the USCS chart the soils under investigation falls in the MH zone, which means that the soils have ‘poor’ engineering properties that are considered unsuitable for various engineering purposes. However, in practice, such soils frequently have good engineering properties especially for construction of sub grades and embankments. Contrary to the USCS, the AASHTO Classification System classify majority of the soils under sub group A-2-7 with a group index less than 4, which mean the soils are good sub grades and embankments construction materials. Using the Wesley’s Classification Method the soils fall under Group C, sub-group (c). Soils under this group have good engineering properties. The soils under investigation have fallen under ferrisols group where erosion has kept pace with profile development.

The analysis of the test results obtained from different laboratory testing procedures used for moisture content, plasticity tests, grain-size analysis and specific gravity tests for the lateritic soils found in Western Ethiopia has shown that the soils are sensitive to the type of testing procedures as a result an appropriate laboratory testing procedures attached in Appendix-A are proposed.

Symbols and abbreviations

Designation	Description	Units
LL	Liquid limit	%
PL	Plastic limit	%
PI	Plasticity Index	%
TSn-1	Test sample number n from the upper part	---
TSn-2	Test sample number n from the middle part	---
TSn-3	Test sample number n from the bottom part	---
LS	Linear shrinkage	%
FS	Free Swell	%
σ	Standard deviation	---
G_s	Specific gravity	---
ω	Moisture content	%
AD	Air drying or samples dried in an oven/other apparatus at a temperature not exceeding 60^{o}C (140^{o}F)	---
OD	Oven drying at a temperature of 105^{o}C	---
S	Soaking (saturation)	---
AR	As received /at the natural moisture content/	---
RH	Relative Humidity	%
AASHTO	American Association of State Highway and Transportation Officials	---
USCS	Unified Soil Classification System	---
ASTM	American Society for Testing and Materials	---

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1. Introduction

1.1 General

Western Ethiopia is predominantly covered by reddish and reddish brown soils which are latreitic and/or undergoing laterization. The examination of the available data on lateritic soils gives the impression that the red color seems to have been accepted by most authors as the most important property by which these soils could be visually identified. For the area under investigation, Nedjo-Jarso-Begi road area, the soil forming factors (e.g. parent rock, climatic vegetation conditions, and topography and drainage conditions) reveals that the soils are laterites. Generally, the formation of laterites favors rolling slope with good water runoff and distinct rainy seasons having warmer summer (Zelalem, 2005; Charman, 1995). For the case of the area under investigation all the soil forming factors are fulfilled. In addition to this, the mineralogical analysis and chemical analysis tests using X-Ray Fluorescent (XRF) and X-RAY Diffraction (XRD) analyses methods confirm that the soils are laterites.

Laterite is the product of a tropical weathering process which has the following effects: the parent rock is chemically changed by enrichment with iron and aluminium oxides; the clay mineral component becomes largely Kaolinitic; and the Silica content is reduced. This process usually produces yellow, ochre, red or purple materials; red is often the predominant color. Even if tropical weathering in oxidizing conditions generally leads to reddening, it does not always produce a lateritic material (Charman, 1995).

The formation of laterites requires hot, humid conditions. It has also been suggested that a mean annual temperature of around 25^oC is needed for their formation, and in seasonal situations there should be a coincidence of the warm and wet periods (Charman, 1995).

Laterites and lateritic soils are generally found in warm, humid and tropical areas of the world. The geotechnical properties of these soils are quite different from those soils developed in temperate or cold regions of the world. The properties of lateritic soils are influenced by climate, geology and the degree of weathering or laterization, hence, pretreatment conditions and testing procedures shall reveal the actual soil properties. The geotechnical properties of such soils in different tropical countries are also different. Lateritic soils formed from the same parent rock in the same tropical country, but under different climatic conditions have different geotechnical properties (Umarany & D.J., 1990). As the properties of lateritic soils measured in the laboratory are affected by type of sample pre-treatments and/or testing procedures such as samples tested under as-received, air-drying, oven-drying temperatures and samples tested under variable mixing times (Umarany & D.J., 1990), the soils property shall be measured using proper testing method.

Some of the engineering properties of lateritic soils of Western Ethiopia have been studied by different researchers, such as Zelalem (2005) has studied lateritic soils found in Nedjo-Mendi areas; Wakuma (2007), Kebede (2008) and G/medhin (2008) have studied the Assosa lateritic soil; and Dibisa (2008) has studied on soils found in Nedjo, Mendi and Assosa areas. In their studies, they had used different sample pretreatments and testing procedures during index tests and came out with different results.

Comparison of moisture contents determined using conventional drying temperature of 105^oC oven temperature and air drying temperature or 50^oC oven temperature (AASHTO T87 – 86) revealed that the lateritic soils found in Nedjo-Mendi areas do not have loosely bound water of hydration in Zelalem (2005); even though, Dibisa (2008) and G/medhin (2008) have found that the soils in Nedjo, Mendi and Assosa areas do have small amount of structural water or water of hydration. In Wakuma (2007) study, the lateritic soils found in Assosa contains a considerable amount of water of hydration.

In the comparison of Atterberg limits tests, the different pretreatment methods during sample preparations do have insignificant effect on Atterberg Limits of Nedjo-Mendi area lateritic soils (Zelalem, 2005), Dibisa (2008) has also found that the different pretreatment methods during sample preparations affect the Atterberg limits of Nedjo, Mendi and Assosa area soils. Wakuma (2007) also found that the soils found in Assosa have been affected by the different pretreatment methods during sample preparations. The soils of Nedjo-Mendi areas have been found susceptible to breakdown with manipulations or elongated mixing times during Atterberg limit tests (Zelalem, 2005). Wakuma (2007) also observed that the soils of Asossa are susceptible to manipulations or elongated mixing times. However, Dibisa (2008) has found that Nedjo, Mendi and Assosa areas soils are not susceptible to manipulations or elongated mixing times during Atterberg limit tests.

In gradation tests comparison, the different sample pretreatments and testing procedures have resulted in negligible difference in grain-size analyses /grading curves/ of Nedjo-Mendi area soils (Zelalem, 2005). In Wakuma (2007), Assosa soils have showed little difference on their gradation distribution curves for variations in pretreatment methods; even, the test results have showed ambiguous results for oven-dried samples. However, lateritic soils of Nedjo-Mendi-Assosa areas were highly affected by pre-test drying than by remolding /testing procedures/ (Dibisa, 2008).

Comparison of specific gravity tests showed that the specific gravity of Nedjo-Mendi area lateritic soils is significantly changed upon drying prior to testing (Zelalem, 2005). Wakuma (2007) has found that the specific gravity of Assosa soils have reduced strongly with higher pre-test oven drying temperatures; however, at lower pre-test drying tempratures the decrease is insignificant. Lateritic soils of Nedjo, Mendi and Assosa areas have shown decrease in the specific gravity upon oven drying temperatures (Dibisa, 2008).

In addition to the above comparision on studies which haven been done on lateritic soils of Western Ethiopia, Tibebu (2008) has done an investigation on the index properties and shear strength parameters of laterite soils found in Southern part of Ethiopia (Wolayita-Sodo). In her investigation, the conventional drying temprature is too high for few samples during moisture content determination as the soils contained loosely bound water of hydration. The different pretreatments have slightly affect the Atterberg limits of the Wolayita-Sodo area lateritic soils even if the soils susceptiblity to breakdown with manipulations or elongated mixing times is limited to these soil samples prepared in air dry pretreatment conditions.

From the comparison of index test results of previous researchers, it can be seen that there is a need for understanding the discrepancy in test results for Western Ethiopia lateritic soils. Tests done by previous researchers have shown that these lateritic soils are very sensitive to the type of pretreatments and testing procedures used. In order to overcome the problems and minimize the discrepancy in testing results it is necessary to investigate the appropriate laboratory testing procedures of these soils. Hence, the index properties of the Nedjo-Jarso-Begi areas have been studied using various testing procedures and pretreatment conditions in order to investigate the appropriate laboratory testing procedures of these red lateritic soils of western Ethiopia. During the study process, the degree of laterization of the soils had been investigated using chemical and mineralogical analyses, which are the criteria for distinguishing lateritic soils from that of non-lateritic or partially laterized soils. In Nejo, Jarso and Begi areas, similar to most of Western Ethiopia, one can consider that the soils are lateritic soils or under gone laterization as all lateritic soil forming factors are fulfilled. The mineralogical tests using X-RAY Diffraction (XRD) analysis method and the geochemical tests using X-Ray Fluorescent (XRF) analysis method showed that the soils are indeed true laterites /lateritic soils/. Once the soil samples have been confirmed that the soils are lateritic soils, index property tests have been carried out on the soil samples collected from the research areas. Then, the sensitivity of the soils for various pretreatment conditions and testing procedures has been investigated. After analyses and comparison of the different testing results, which used different pretreatments and testing procedures, appropriate laboratory testing procedures are proposed in this research work.

1.2 Objectives of the study

1. Investigation of the appropriate laboratory testing procedures for the determination of the index properties of the lateritic soils of Western Ethiopia
2. Determination of the Index Properties of the lateritic soils of the given research area

1.3 Methodology of the study

In this research, the sensitivity of the lateritic soils to test procedures during determination of the index properties of the soils was investigated. Lateritic soils are sensitive to the way in which they are prepared for laboratory testing and to the actual testing method employed. This sensitivity can be attributed to three basic factors, namely aggregation of clay-size particles, irreversible changes in plasticity on drying and loss of water of hydration on drying.

The susceptibility of tropical soils to the effects of clay mineral aggregation, to drying and re-wetting cannot be identified by simple inspection. It requires elaborate testing procedure. To address this sensitivity the following test methods were employed.

A large bulk samples (29 samples each weighing about 20-25kg) of material were collected from each test pits /sample sources/ along Nedjo-Jarso-Begi road route and transported to the laboratory at their field moisture content. Each sample shall then be separated into test portions using proper quartering technique for the of index tests.

For the investigation of loss of water of hydration; samples which were oven dried at 105^{o}C and air drying (or 50^{o}C oven dried) were used. The two results should then be compared; a significant difference (4-6%, Blight, 1997) indicates that the material contains structural water which does play a part in the field performance of the soil. If this difference is confirmed by repeated tests then the oven-drying temperatures for the subsequent programme of tests should be changed to an appropriate value.

For the investigation of the effects of pretreatments, i.e. disaggregation of clay-size particles on mixing and, drying and wetting pretreatments, different techniques were used. For the investigation of disaggregation of clay-size particles upon mixing, five air-dried/oven-dried/as-received samples had been mixed with water from every sample sources to give the range of water contents suitable for liquid limit and plastic limit determinations. The mixing times for the liquid limit tests were limited to 5 minutes, and the mixed samples were left to dry overnight before testing. After the moisture content for each test point on a part of each test portion were determined, the reminder had then been mixed for further 25 minutes before determining the liquid limit again. If a significant difference between the liquid limits of the specimens with 5 minutes and 25 minutes mixing times occurs, it indicates that there is a disaggregation of clay-sized particles within the material. For the case of investigating effects of drying and wetting pretreatment testing procedures on index testing, different samples which were air-dried (AD), oven-dried (OD) and As–received (AR) /at natural moisture content/ had been used for index tests and finally comparison were made to investigate the appropriate testing procedures.

Geochemical tests were carried out on six samples at Geological Survey of Ethiopia Geochemical Laboratory using X-Ray Fluorescent (XRF) analysis method in order to determine the percentage of oxide composition of the soils under investigation. In addition to the above test, a mineralogical analysis was made on six samples at Geological Survey of Ethiopia Mineralogy and Petrography Laboratory using X-Ray Diffraction (XRD) analysis method in order to determine mineralogical composition.

1.4 Structure of the Thesis

The thesis has been divided in to six Chapters. The first Chapter is the introductory part which includes the general background, objective and methodology of the study. A brief literature reviews on formation, distribution, sensitivity of laterites to testing procedures and laterites as a construction materials has been discussed in the second Chapter. In the third Chapter description of the sampling area is covered which includes geology, climate, topography, vegetation and land use of the area. The fourth Chapter includes in-situ Properties, Laboratory tests and results; moreover a laboratory testing procedures which is more likely appropriate for the respective index tests has been recommended. Comparison of test results with other lateritic soils and discussions of test results and test procedures are presented in the fifth Chapter. In the last Chapter, Chapter six, conclusions and recommendations which are drawn from this research are given. Finally, appendices and references are attached at the end of the thesis.

2. Literature Review

2.1 General

Laterite is the result of decomposition or weathering process and is found in profiles varying from fresh rock at deep depths, through various stages of decomposition, to residual soil at the surface. The term has been applied to clays, sands and gravels in various combinations, and to rock of different degrees of cementation (Charman, 1995).

Laterites have also been defined based on the ratios of silica (SiO_2) to sesquioxides (Fe_2O_3, Al_2O_3). As laterites are usually highly weathered and altered residual soils, they are low in silica (SiO_2), that contain a sufficient concentration of the sesquioxides of iron and aluminium (Fe_2O_3 and Al_2O_3) to have been cemented to some degree. For laterites/true laterites the silica: sesquioxide ratio is below 1.33, those between 1.33 and 2.00 are lateritic soils, and those greater than 2.00 are non-lateritic tropically weathered soils (Lyon Associates, 1971).

Laterite soils are formed in hot, wet tropical regions with an annual rainfall between 600mm to 4000mm, (usually in areas with a significant dry season) on a variety of different types of rocks with high iron content (Lyon Associates, 1971; Makasa, 1998).

Two aspects of the parent rock affect the formation of laterites. One is the availability of iron and aluminium minerals. These are more readily available in basic rocks. The other is the quartz content of the parent rock. Where quartz is a substantial component of the original rock, it may remain as quartz grains. Laterite profiles occur on flat slopes in the terrain where runoff is limited. On the level ground, where drainage is poor, expansive clays dominate at the expense of laterites (Makasa, 1998; Charman, 1995).

From the above discussions, we see that three major processes can be identified during the formation of laterites which are summarized as follows:

Decomposition: physico-chemical breakdown of primary minerals and the release of constituent elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, etc), which appear in simple ionic forms.

Laterization: leaching occurs under appropriate conditions where combined silica and bases and the relative accumulation or enrichment of Oxides and Hydroxides of

Sesquioxides (Fe_2O_3, Al_2O_3, and TiO_2) exists. The soil conditions under which the various elements are rendered soluble and removed through leaching or combination with other substances depend mainly on the pH of the ground water and the drainage conditions (Makasa, 1998; Dibisa, 2008).

Desiccation: desiccation or dehydration involves partial or complete dehydration (sometimes involving hardening) of the Sesquioxide rich materials and secondary minerals. The dehydration of colloidal hydrated Iron oxide involves loss of water and the concentration and crystallization of the amorphous Iron colloids into dense crystals, in the sequence; Limonite, Goethite with Hematite to Hematite (Makasa, 1998).

Dehydration may be caused by climatic changes, upheaval of the land, or may also be induced by human activities, for example by clearing of forests.

Lateritic soils have specific features or characteristics that are not adequately covered by conventional methods of soil classification such as the Unified Soil Classification System. Among these features are the following (Blight, 1997),

1. The unusual clay mineralogy of some tropical and subtropical soils results in characteristics that are not compatible with those normally associated with the group to which the soil belongs according to existing systems such as the Unified Soil Classification System.
2. The soil mass in-situ may display a sequence of materials ranging from a true soil to a soft rock depending on the degree of weathering, which cannot be adequately described using existing systems based on classification of transported soils in temperate climates.
3. Conventional soil classification systems focus primarily on the properties of the soil in its remolded state; this is often misleading with residual soils, whose properties are likely to be most strongly influenced by in situ structural characteristics inherited from the original rock mass or developed as a consequence of weathering.

Wesley L.D. and Irfan T.Y. (Blight, 1997) proposed a practical system for classifying all residual soils, based on the mineralogical composition and soil micro- and macro-structure. Wesley's classification system is intended to provide an orderly division of residual soils in to groups which belong together because of common factors in their formation and/or composition which can be expected to give them similar engineering properties. The system is based on a grouping framework designed to enable engineers to find their way around a rather confused world of residual soils and enable them to place any particular residual soil into a specific category on the basis of common engineering properties.

The first step in the grouping of residual soils is to divide them into groups on the basis of mineralogical composition alone, without referring to their undisturbed state. The following three groups are often suggested (Blight, 1997; Dibisa, 2008):

1. *Group A:* Soils without a strong mineralogical influence, e.g., Saprolites (Residual soil with clear structural feature inherited from its parent rock).
2. *Group B:* Soils with a strong mineralogical influence deriving from clay minerals also commonly found in transported soils (Black Cotton Soils).
3. *Group C*: Soils with a strong mineralogical influence deriving from special clay minerals only found in residual soils (i.e. based on the silicate clay minerals, halloysite and allophone, and non-silicate minerals ('oxide' minerals) which are the hydrated forms of aluminium and iron oxide (the sesquioxides), gibbsite and goethite).

Laterites classification is also possible according to their genetic basis, size of particle and degree of concretion/cementation. Besides the grouping system presented above, an additional item of formation which is usually of major importance in influencing the properties of residual tropical soils is the type of the parent rock and should always be included in the grouping processes. Most of the residual soils of Africa can be divided into three groups based on their genetic basis, determined by the soil-forming factors and given below: (Lyon Associates, 1971)

i. *Ferruginous Soils:* occur in the more arid extremes for lateritic soils, in areas with pronounced dry seasons. They are formed over all rock types: igneous, metamorphic and sedimentary. It requires an average annual rainfall of *600-800 mm* for its formation.

ii. *Ferrallitic Soils:* These soils in the humid extremes for lateritic soils and in areas with dense vegetation. These soils are also formed over all rock types. The annual average rainfall requirement for its formation is *1500- 4000mm*. Both of the above soils have SiO_2 / (Fe_2O_3 + Al_2O_3) ratio of less than 2.0 and are classified either as lateritic or laterite soils.

iii. *Ferrisols:* These are formed over all types of rocks in intermediate to high rainfall areas where erosion has kept the place with profile development. They have similar profiles to ferrallitic soils, but with few weatherable minerals remaining. The entire clay fraction comprises Kaolinite and amorphous oxides of iron and aluminum. These are developed at deeper levels due to the surface erosion, and occur in regions of annual average rainfall of *1250-2750mm*.

The usual methods of soil classification, involving grain-size distribution and Atterberg Limits, should be performed on laterites or suspected laterites that are anticipated for use as fill, base-course, or surface-course materials. Consideration should be given to the previously stated fact that some particles of laterite crush easily; therefore, the results obtained depend on such factors as: the treatment of the sample, amount of breakdown, and the method of preparing the sieve material. The more the soil structure is handled and disturbed, the finer the aggregates become in grading and the higher the Atterberg Limit. While recognizing the disadvantage of these tests, it is still interesting to note the large spread and range of results for both laterites and lateritic soils (Dibisa, 2008).

2.2 Properties and testing of laterites

In tropical areas, where chemical weathering is often intense, the availability of suitable rock as a source of crushed aggregate may be limited. Considerable savings can be achieved by using local materials, even though these may appear to be of marginal quality when judged by certain specification using conventional testing procedures. In these areas laterite has been a traditional source of road stone aggregate, mostly in the form of nodular laterite /lateritic gravels/ (Charman, 1995).

The material properties most relevant to the satisfactory performance of natural gravels in road pavements are particle size distribution, plasticity, strength of the coarse particles and compaction and bearing strength. The principal selection requirement in traditional specification is suitable grading. This allows visual assessment of suitable material sources. The specified grading effectively limits potentially suitable lateritic materials either to nodular lateriteis, containing a significant coarse component or to honeycomb and hardpan laterites, which can be processed to the required grading.

Another aspect of lateritic materials which may be relevant is the concept of self-hardening or a time-dependent improvement in performance. Some laterites, such as Plinthite, are too fine-grained to be accepted as a pavement material at present, but may have an important role to play in highway engineering if they can be found to show a time-dependent or construction-dependent improvement in performance. Large cost savings could be made by using these soils in an improved sub-grade layer, for example, thereby reducing the thickness of the overlying pavement. The factors involved in self-hardening may also make these soils sensitive to the procedures used in preparing samples for testing and to testing methods themselves (Charman, 1995).

2.2.1 Traditional selection and performance criteria

In many tropical countries the temperate zone specification and the conventional testing procedures have been adopted for the selection and evaluation of highway materials. However, in some tropical countries many lateritic gravels have been successfully used in road pavements; such as Nedjo-Jarso-Begi (Ethiopia), M9 Ondo to lfe (Nigeria), Lethem (Guyana) and Umuatria to Bende (Nigegia), despite the fact that they do not comply with the temperate zone specification requirements for particle size distribution, plasticity characteristics, and sometimes CBR. A specification and appropriate laboratory testing procedures should be used for the use of tropical soils in road pavements, based on the genesis of the soils and the climatic environment.

2.2.1.1 Particle size distribution

The successful use of laterites in pavement constructions depends largely upon their grading; not only may this be changed by the construction processes it may also be changed by the testing methods. A clear understanding of the conventions implicit in the test and calculation methods is therefore fundamental to the assessment of any analysis of particle size (Charman, 1995).

One of these conventions is the assumption of a constant specific gravity for the soil particles; when determined by measurement this value is usually an average over the full range of particle sizes. For some laterites, whose coarse fraction is iron-rich and whose fine fraction is kaolinite, this convention may be misleading. The coarse fraction usually has a specific gravity of between 3.0 and 3.5 (but sometimes very much higher), while the specific gravity of the finer material is about 2.7. The particle-size distribution curve is based on proportions by mass retained on successive sieves, and only represents a particular packing arrangement for a soil of constant specific gravity. Given this discrepancy in specific gravity, a conventionally calculated test applied to some laterities would overestimate the volume content of coarser particles and exaggerate any gap-grading in the material, and would not represent the true packing and mechanical stability of the material as a whole (Charman, 1995).

It is important therefore, when judging grading analyses to inspect the material assess its composition and decide if separate specific gravity determinations of the fine and coarse fractions shall be made. If the specific gravities are significantly different, the grading should be calculated by modified mass proportions as well as by mass proportions as this procedure will give a clearer indication of the potential mechanical stability of the compacted aggregate (Charman, 1995).

In addition to this, relatively weak coarse particles may also cause problems in grading analyses. Hence, for the analysis to represent the source material the sample preparation and test procedures should not fracture the coarse particles. It is also equally important that the fines adhering to the coarse particles shall be removed (Charman, 1995; Lyon Associates, 1971).

2.2.1.2 Plasticity characteristics and testing

The plasticity of laterites varies widely, both from deposit to deposit and within a deposit. Laterites are very variable in their plasticity characteristics. They are ranging from non-plastic to highly plastic laterites; hence, each material source should be evaluated independently and published data should not be held typical of laterites in general (Charman, 1995).

For temperate region soils, Atterberg Limits are established indicators of engineering behavior. However, for tropical soils they can be highly misleading without an awareness of the sensitivity of these soils to the testing procedures as a high proportion of hydrated oxides can change the properties of the fine fraction. Any sensitivity should be an initial series of tests. A scheme for such a series of tests is also discussed later.

2.2.2 Effect of pre-treatments

2.2.2.1 Effect of pre-test drying

Some lateritic soils show changes in physical properties when tested under different conditions. Oven-drying, and even air-drying, affects the properties of soils, although the effect is usually small for transported soils. Tropical soils are prone to changes in properties caused by drying and exposure to air. Hence, index property and engineering property tests should be done by simulating the actual site conditions (Blight, 1997).

The water of hydration in the sesquioxides of iron and aluminum may be driven off by oven drying at 105^{o}C. This water of hydration normally takes part in the engineering performance of the material, but is reflected in the test results as higher moisture content. In order to be meaningful, Atterberg limit tests should therefore be performed without any form of drying prior to carrying out the tests (Blight, 1997).

As the specific gravity is used to calculate parameters like clay fraction, void ratio and porosity and the specific gravity of residual soils may be unusually high or unusually low, it is essential that the specific gravity of these soils be determined in the laboratory using an accepted test procedure. The soil to be used in this test should be at its natural moisture content. Pre-test drying should be avoided as this tends to reduce the measured specific gravity. The dry mass of the soil used in the test should be calculated by drying the soil specimen after the specific gravity test has been completed. Depending on the outcome of the evaluation of presence or absence of water of hydration, it may be necessary to air-dry or dry at a reduced temperature while computing the dry mass of the soil (Blight, 1997).

2.2.2.2 Effect of method and duration of mixing for Atterberg limit

In general, the greater the duration of mixing (i.e., the greater the energy applied to the soil prier to testing), the larger the value of the liquid limit, and to a lesser extent, the larger the plasticity index. This has been attributed to longer mixing resulting in more extensive break down of the cemented bonds between the clay clusters and within peds and thus formation of greater proportions of fine particles (Blight, 1997).

2.2.3 The concept of self-hardening

The property of self-hardening, i.e. time-dependant or construction dependant improvement in performance, under cycles of wetting and drying could be important for the performance of certain lateritic soils. Any potential improvement in performance as a result of self-hardening would be expected to relate to the proportion of oxides present in the matrix, and therefore to vary according to maturity or degree of cementation (Charman, 1995).

Some evidence now exists to suggest that certain laterites exhibit this property to a sufficient extent that traditional requirements governing the selection of materials may be relaxed. Materials which are normally considered mechanically unstable and too plastic may be satisfactory. For instance, Brazilian practice uses the silica: sesquioxide (s-s) ratio as a selection criterion for pavement aggregates and differentiates certain materials as lateritic gravels on the basis of this ratio begin less than 2, allowing a relaxation in specification requirements compared with British and African practice.

The factors which influence the ability to self-harden may also affect the sensitivity of certain lateritic soils to test procedures. There is no doubt that certain of these soils are sensitive to the way in which they are prepared for laboratory tasting and to the actual testing method employed.

2.2.3.1 Aggregation of clay-size particles

Different authors showed that the sesquioxides within the fine fraction of tropical soils tend to coat the surface of individual soil particles. One reason for this is an electrical bonding between the negatively-charged kaolinite and the positively-changed hydrated oxides. The coating can reduce the ability of the clay minerals to absorb water. It can also cause a physical cementation of adjacent grains, thus producing aggregated particles of coarser size. Both factors reduce plasticity, but intensive remolding of the soil breaks down the aggregations and the sesquioxide coatings, with an attendant increase in plasticity (Charman, 1995; Blight, 1997).

The field operations of excavation, transport and placement are unlikely to break down the fine soil aggregations to the extent that plasticity is affected in the laboratory. The degree of working required to prepare laboratory specimens for Atterberg Limit determinations is, by comparison, very much greater. The plasticity of the construction material (the soil on site) may thus be lower than would appear from the Atterberg or other laboratory tests on remolded samples.

2.2.3.2 Irreversible changes in plasticity on drying

Soils which contain hydrated oxides of iron and aluminum may become less plastic (i.e. exhibit lower Atterberg Limit values) when they are dried. This is partially because dehydration of the sesquioxides creates a stronger bond between the particles, which is resistant to penetration by water. Another aspect is accompanied by shrinkage, which brings the particles closer together and the attractive forces become so strong that water no longer penetrates. The effect takes place during air-drying but becomes more pronounced on oven-drying at higher temperatures (Charman, 1995; Blight, 1997).

2.2.3.3 Loss of water of hydration on drying

The water of hydration in the sesquioxides of iron and aluminum may be driven off by oven-drying at 105^{o}C, conventional drying temperate. This water normally takes no part in the engineering performance of the material, but is reflected in the test results as higher moisture content (Charman, 1995; Blight, 1997).

2.2.4 Identification of sensitivity to testing procedures

The susceptibility of tropical soils to the effects of clay mineral aggregation, to drying and to re-wetting (dehydration of sesquioxides) cannot be identified by simple inspection. To make wholesale changes to standard laboratory techniques, however, would considerably lengthen testing times and require full-time supervision of the testing laboratory. An initial test programme on a representative bulk sample from each material source is therefore needed to identify the sensitivity of the soil to the above factors (Charman, 1995; Blight, 1997; Lyon Associates, 1971).

A large bulk sample of material should be selected from each new source and transported to the laboratory at field moisture content. This sample should then be separated into replicate test portions for the following tests.

2.2.4.1 Loss of water of hydration

In order to check loss of water of hydration two specimens should be prepared for the determination of moisture content. One specimen should be oven-dried at 105^{o}C until successive weighing show no further decrease in mass. The moisture content should then be calculated. The second sample should be air-dried (if feasible), or oven-dried at temperature of no more than 50^{o}c and at maximum relative humidity (RH) of 30% until successive weighing show no further loss of mass. The two-moisture contents should then be compared. A significant difference (4-6%) indicates that “Structural water” is present. As this water forms part of the soil solids, it should be excluded from the calculation of moisture content. Hence, all subsequent tests for moisture content determination (including those associated with Atterberg limit tests, etc.) should be carried out by drying at the lower temperature (i.e. either air-drying, or oven–drying at 50^{o}C and 30% RH). If possible, the lower drying temperature should be used (Blight, 1997).

2.2.4.2 Disaggregation of clay-size particles on mixing

In order to address the problem of disaggregation, five test specimens should be mixed with water to give a range of moisture contents suitable for liquid limit and plastic limit determinations. The minimum amount of air-drying should be used, and preferably none at all. The mixing time should be standardized at 5 minutes, and the mixed specimens should be left for moisture content equilibration overnight before testing.

On the following day the liquid limit should be determined using the standard procedure (e.g. British Standard 1377, Part 2) with a minimum of further mixing. A sub-sample from each of the specimens used in the test should be used for determining the moisture content, using the appropriate procedure established after the evaluation of presence or absence of water of hydration discussed previously. The remainder of each specimen should then be mixed continuously for a further 25 minutes before determining the liquid limit. A significant difference (i.e. >5%) between the liquid limits from tests using 5 and 30 minutes mixing times indicates a disaggregation of the clay-sized particles in the soil. If this disaggregation is confirmed by further tests, the entire procedure of testing should be changed (Blight, 1997).

2.2.4.3 Drying and wetting

According to CIRIA special publication vol. 47 (Charman, 1995) research is in progress to assess the effect of drying and wetting cycles on the dry density and bearing strength of lateritic materials. Even though there is no simple test available for this, some guidance may be obtained by comparing the Atterberg Limits of soil prepared from natural moisture content with those of oven-dried soil re-wetted to the point of testing.

2.3 Laterites as construction materials

Some laterites are valuable road pavement materials, widely used in the tropics as sub-base, base material and for gravel wearing roads. The term laterite, however, has tended to be indiscriminately applied in tropical highway engineering to any red soil, and as a result the usefulness of laterites for road construction has been under-estimated (Charman, 1995).

However, laboratory tests, to check the suitability of laterites as road pavement materials, should take into account how these materials are affected by the testing procedures. Some lateritic soils are sensitive to pre-treatments and testing procedures; hence, laboratory testing should simulate the site condition (Charman, 1995; Zelalem, 2005).

3. Sampling Area Description

3.1 General

The sampling area, Nedjo-Jarso-Begi road, is situated in South Western Ethiopia in western Wellega Administrative zone of the Oromiya Regional State (Ref. Annex 1.1: Location Map). The road is one of the important routes that pass through vast and fertile land of the Country. Furthermore, it is the major road link that may joins the planned western Ethiopia road corridor (Gambella - Assosa road) at Begi town. The western Ethiopia road corridor is a major inter - regional link between Benishangule, Oromiya and Gambella regional states and its location is also in close proximity with the border towns of the Sudan. The beginning of the road is marked as km 0.0 at Nedjo town and terminates is at Begi town on the junction to Gidame. The end point of the project (Begi town) is accessible by a road from Gimbi-Dembi-dollo main highway, through Chanka via Gidame. It is also accessible through Bambassi via Kober village. The total project length is about 148.2 km (AEC, 2004).

The client of the project is Ethiopian Roads Authority (ERA). Currently the road is under construction by Sunshine General Contractor Plc. consulted by Highway Engineers and Consultants/HEC/ Consulting Engineers Plc. The Project is funded by Federal Government of Ethiopia.

3.2 Geology

According to the Geological Map and field observation of the route corridor the project alignment is dominantly covered by basalt with minor granite/granodiorite, schist and recent alluvial deposits. A brief summary of the geological units along the project route corridor is given below in table 3.1.

Table 3.1 Summary of Geology of the Route Corridor (AEC, 2004)

Location (km)	*Route Geology and Geomorphology*
0.0 to 2.5	Hilly to ridge, qurthofeldspathic schist with associated quartz veins formation
2.5 to 78.0	Flat topped to hill, massive to widely jointed basalt formation
78.0 to 87.0	Flat lying to hill, massive to widely jointed basalt with pockets of dark silty clay soils (alluvial origin) formation
87.0 to 95.0	Flat lying to hill, massive to widely jointed basalt formation
95.0 to 99.5	Ridge, granite / grandodiorite formation
99.5 to 148.2	Flat lying to hill forming massive to widely jointed basalt formation

3.3 Climate

In terms of climate the project area can be broadly classified in to two climatic zones. Zone 1: warm to Temperate, km 0.0 to 50 (Babo) and km 110 to 148.2 (Begi) and Zone 2: warm to Hot (kola), km 50 to 110.

Table 3.2 Summary of mean maximum and minimum temperature along the project route (AEC, 2004)

Town	Temperature (^oC)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Nedjo	Mean Max	27.3	28.9	29.6	28.5	25.5	23.5	21.8	22.0	23.6	23.9	25.2	26.1
	Mean Min	8.6	9.8	12.1	13.7	14.1	14.2	13.7	13.3	13.2	11.9	10.3	9.2
Begi	Mean Max	29.3	29.8	29.7	28.9	25.7	24.2	23.1	23.4	24.3	25.0	26.1	27.0
	Mean Min	14.1	15.0	15.0	15.1	14.5	13.8	13.5	13.6	13.6	13.3	13.3	13.1

According to the Meteorological data the mean minimum and maximum annual temperatures for Zone 1 lies between 12 to 14^{o}C and 25 to 26^{o}C respectively. For Zone 2 the annual mean temperature is about 30^{o}C owing to its elevation, 1350 to 1500m above sea level. The project corridor generally has an effective mean temperature of 14 to 20^{o}C (AEC, 2004).

The mean annual rainfall varies from 1200mm at around Dabus crossing to around 2000mm at Nedjo and Begi towns (i.e. it ranges 1200-2000mm). Significant rain can be expected in the area, from the month of April to October, inclusive, with peaks around July and August. During the remainder of the year there is very little precipitation (AEC, 2004).

3.4 Topography

In general, the topography of the route corridor is almost in all cases rolling to hilly terrain from the beginning until the end of the project. The project starts at an altitude of 1840 m asl at Nejo and descends to 1350 m asl at around Dabuss river basin. It then ascends to 1718 m asl towards the end of the project at the vicinity of Begi town.

The topography of the road route corridor is almost all flat to rolling terrain from the beginning (Nedjo town) to the end of the project (Begi town) which is favorable to the formation of lateritic soils.

3.5 Vegetation and Land use

The land use/cover along the existing route corridor as well as the accessible sections can generally be classified as moderately cultivated land and grazing land in between farms.

The project areas are covered by dense woodland, Farms and scattered trees with Scrubs in the first half of the project route; and Farms and Grass lands mixed with scattered woodlands, dense woodlands and forests.

Table 3.3 Summary of land cover along the project route (AEC, 2004)

Station	Land Cover
0+000 – 0+600	Dense woodland
0+600 – 60+500	Farm and scattered trees
60+500 – 65+000	Scrubs mixed with Farm
65+000 – 70+500	Farm and Grass lands mixed with scattered woodlands
70+500 – 76+000	Farm and scattered woodlands
76+000 – 86+000	Woodlands
86+000 – 94+000	Scrubs
94+000 – 103+000	Bamboo (dense woodlands)
103+000 – 107+000	Farms and dense forests
107+000 – 122+000	Woodlands
122+000 – 134+000	Farms and scattered trees
134+000 – 148+226	Farmlands

A strip of Eucalyptus trees which are planted along the road side are also found in dense condition. On the other hand the portion from Sedeka River to Guma Gara arba is forest.

The route corridor between Nedjo and Dabus and between Likiti and Begi is moderately populated, while the area between Dabus and Likiti is sparsely populated due to its remoteness and hot climatic condition. Farming is a common practice along the populated area. Cereals, oil seeds and coffee are the most common cash crops.

3.6 Soil Characteristics

Western Ethiopia, Wellega zone along the route Nekempte–Gimbi–Nedjo–Mendi–Assossa; and Nedjo–Jarso–Begi road routes are covered with reddish soils. The existing soil formation factors such as topography, climate, temperature, rainfall, and parent rock seem to favor laterites formation. Generally, formation of lateritic soils favors rolling slope with good water runoff, distinct rainy season having warm summer. The minimum annual rainfall required for laterites formation is generally at least 750 mm. For the research area, Nedjo–Jarso–Begi road, as mentioned in section 3.4 the slope is flat to rolling type and about 80% of the mean annual rainfall occurs during the period of 4 months which is seasonal. The rain fall on the average annual basis is equals 1200mm at around Dabus to around 2000mm at Nedjo and Begi towns which is in agreement with the minimum requirement as mentioned above.

Geologically, the area under consideration comprises of the rock types granite, metamorphic rocks including gnesis and schist, and mainly basalts which are basis for lateritic soil formations. By comparing the lateritic soil formation factors and the actual soil information of the research area with the supplement of previous researcher data of western Ethiopia is highly covered with lateritic soils, even though the degree of laterization could vary from place to place.

Laterite soils are formed by the in-situ weathering and decomposition of rocks under tropical condition. They are rich in sesquioxides (secondary oxides of iron and/or aluminum) and low in bases and primary silicates but may contain appreciable amounts of quartz and kaolinite. Soil engineering properties under this group are highly influenced by the presence of sesquioxides. Sesquioxides appear to act as cementing agents which bind the other mineral constituents into clusters or aggregations.

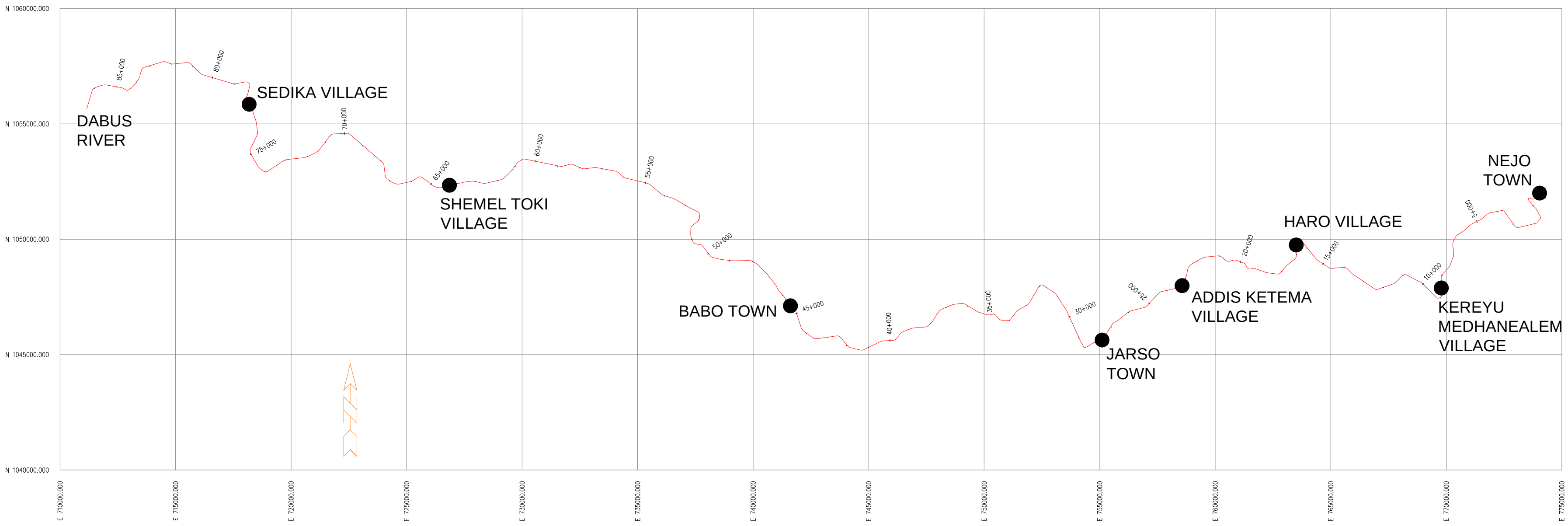

Figure 3.1 Schematic diagram of Nedjo – Jarso – Begi area (Nedjo-Dabus River)

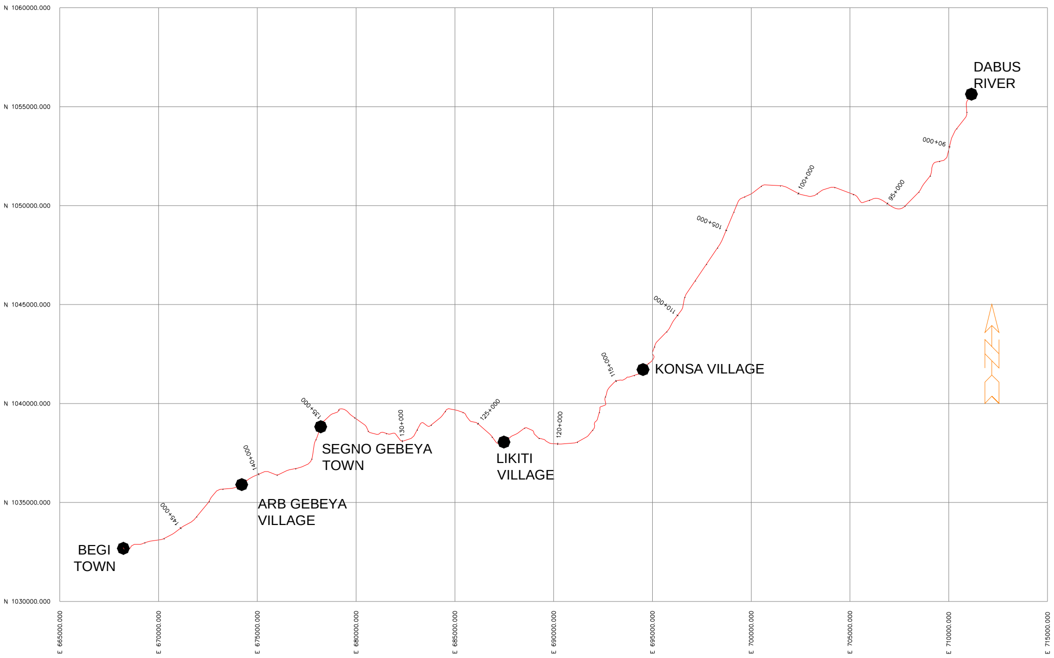

Figure 3.2 Schematic diagram of Nedjo – Jarso – Begi are (Dabus River-Begi)

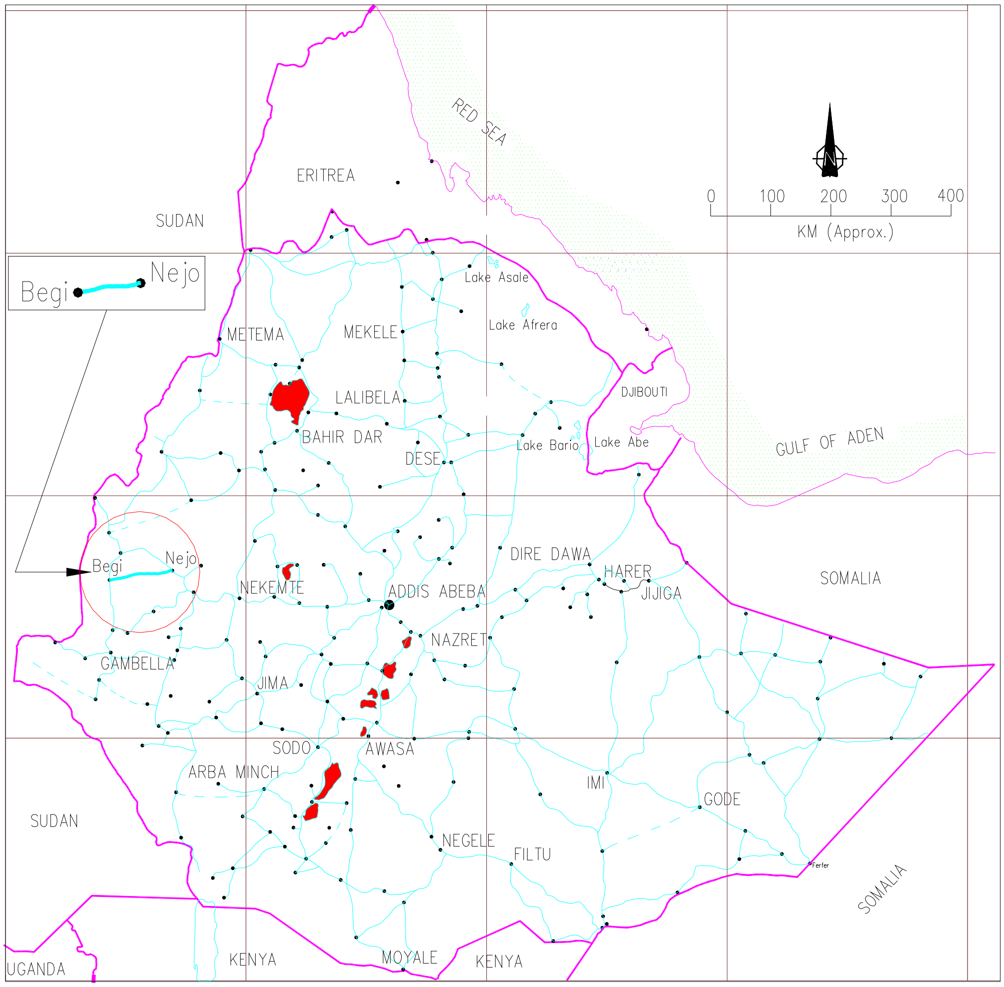

Figure 3.3 Location map of Nedjo – Jarso – Begi area (AEC, 2004)

4. In-situ Properties, Laboratory tests, results and discussions

4.1 In-situ properties

4.1.1 Sample Description

Soil samples used for this thesis work were collected along the stretch from Nedjo town (515km) to Dabus River (605km) west of Addis Ababa, the capital city of Ethiopia. At the time of sampling it was difficult to continue soil sampling after Dabus river as the road was not accessible and the construction of the road beyond Dabus River was not started. Hence, all samples for this research work were collected from Nedjo town to Dabus River which covered 90km of the area. Before the soil samples were collected, site visit was made with consultant's material inspectors and surveyors (of Nedjo-Jarso-Begi road construction project). During the site investigation potential sampling places for lateritic soils were chosen. Accordingly, different sampling places were chosen; and twenty nine samples had been collected on the following days, each weighing about 20-25kg.

Table 4.1 Sample location, depth and the designation used for the samples

S/No.	Sample Designation	Sample Location		Visual Color observed	Sampling area
		[1]Station	Depth		
1	[2]TS1-1	10+880, 1.5km RHS	0.6m	Reddish Brown Color	Test Pit
2	TS1-2	10+880, 1.5km RHS	2.0m	Yellowish Color	Test Pit
3	TS2-1	16+280, 20m RHS	1.5m	Reddish Color	Road cut section
4	TS2-2	16+280, 20m LHS	3.0m	Yellowish Color	Road cut section
5	TS3-1	20+000, 50m RHS	0.6m	Dark Brown Color	Test Pit
6	TS3-2	20+000, 50m RHS	2.0m	Reddish Color	Test Pit
7	TS4-1	30+000, 20m RHS	2.0m	Reddish Color	Road cut section
8	TS4-2	30+000, 20m RHS	3.0m	Yellowish Color	Road cut section
9	TS5-1	35+980, 120m RHS	0.6m	Dark Brown Color	Test Pit
10	TS5-2	35+980, 120m RHS	1.8m	Reddish Color	Test Pit
11	TS5-3	35+980, 120m RHS	2.5m	Greyish Blue Color / Grey and yellow motted color	Test Pit
12	TS6-1	44+080, 40m LHS	1.0m	Dark Brown Color	Test Pit
13	TS6-2	44+080, 40m LHS	2.0m	Yellowish Color	Test Pit
14	TS7-1	49+100, 20m LHS	1.5m	Reddish Color	Road cut section
15	TS7-2	49+100, 20m RHS	3.5m	Yellowish Color	Road cut section
16	TS8-1	53+000, 40m RHS	1.5m	Reddish Color	Test Pit
17	TS8-2	53+000, 40m RHS	3.0m	Yellowish Red Color	Test Pit
18	TS9-1	58+000, 50m LHS	0.6m	Dark Brown Color	Test Pit
19	TS9-2	58+100, 50m LHS	1.5m	Reddish Brown Color	Test Pit
20	TS10-1	58+200, 200m LHS	0.6-1.5m	Reddish Brown Color	Borrow quarry site
21	TS11-1	58+200, 250m LHS	1-2m	Reddish Brown Color	Borrow quarry site
22	TS12-1	70+040, 300m RHS	1-2m	Reddish Color	Borrow quarry site
23	TS13-1	70+840, 20m LHS	1.0m	Dark Brown Color	Road cut section
24	TS13-2	70+840, 20m LHS	3.0m	Yellowish Color	Road cut section
25	TS14-1	74+300, 30m RHS	1.0m	Dark Brown Color	Road cut section
26	TS14-2	74+300, 30m RHS	1.5m	Reddish Brown Color	Road cut section
27	TS14-3	74+300, 30m RHS	3.0m	Light yellow color/Grey and yellow motted Color	Road cut section
28	TS15-1	84+200, 200m RHS	1-2m	Reddish Brown Color	Borrow quarry site
29	TS16-1	84+200, 200m RHS	1.0m	Reddish Brown Color	Borrow quarry site

As sampling places of TS10-1, TS11-1, TS12-1, TS15-1 and TS16-1 were used as a source of borrow materials and the soils were uniformly mixed, only one test sample was taken from every sampling places.

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[1] Station 0+000 is at Nedjo town which is app. 515 km, from Addis Ababa

[2] TS refers “Test Sample”

a) Sampling source for test samples TS10-1 & TS11-1

b) Pit for test samples TS5-1, TS5-2 & TS5-3 samples

C) Pit for TS6-1 & TS6-2 test

Figure 4.1 Profile view of soil sample pits or sources

4.1.2 In-situ properties Description

From the sampling area, samples were collected at their moist condition using plastic bags. The plastic bags were tied to reduce loss of moisture. In-situ moisture contents were determined immediately, after the samples were brought to the laboratory, using oven temperatures of 50°C and 105°C for every test samples. Each sample was dried in oven until continuous weighing gives constant weight. For 105°c oven drying temperature, every sample was dried for 24 hrs where as for 50°c oven temperature the samples were dried for five days. The summary of the in-situ moisture contents of the samples for both drying temperatures are presented below in Table 4.2.

Table 4.2 In-situ moisture contents of the samples using 50°c and 105°c oven temp.

Sample Designation	In-situ/Natural Moisture contents, NMC (%)		Difference (%)
	Using 50°C oven temp.	Using 105°C oven temp.	
TS1-1	33.74	35.13	1.39
TS1-2	30.11	33.79	3.68
TS2-1	24.7	27.23	2.53
TS2-2	17.98	21.24	3.26
TS3-1	22.99	26.63	3.64
TS3-2	27.52	31.36	3.84
TS4-1	24.97	28.79	3.82
TS4-2	21.87	24.97	3.1
TS5-1	31.1	32.37	1.27
TS5-2	23.16	24.51	1.35
TS5-3	27.99	30.19	2.2
TS6-1	12.69	16.29	3.6
TS6-2	16.51	20.44	3.93
TS7-1	25.12	28.86	3.74
TS7-2	31.89	35.44	3.55
TS8-1	15.8	17.61	1.81
TS8-2	16.68	20.22	3.54
TS9-1	33.07	36.1	3.03
TS9-2	12.86	16.63	3.77
TS10-1	15.12	19.06	3.94
TS11-1	32.5	35.92	3.42
TS12-1	13.27	17.05	3.78
TS13-1	17.42	21.02	3.6
TS13-2	19.94	23.9	3.96
TS14-1	15.32	17.64	2.32
TS14-2	13.97	16.13	2.16
TS14-3	14.62	16.75	2.13
TS15-1	21.32	23.61	2.29
TS16-1	15.89	18.37	2.48

4.1.3 Variation of Soil Properties within Profiles

The variation of soil properties along the profile were investigated for the research area. During sampling process it was observed that the soils generally became coarser while excavating down ward. This observation was also confirmed during the laboratory testing process. The particle size of the soil samples (the percentage of clay, silt, sand and gravel) in a given profile are summarized in Table 4.3. In addition to particle size distribution, variation of plasticity index and natural moisture contents within the profile are also included in the table below. In general, the amount of fines decreases as the depth increases.

Table 4.3 Variation of particle sizes, PI and NMC within profile

Sample Designation	Depth (m)	Percentage amount of particle sizes				NMC (%)	PI (%)
		Gravel (%)	Sand (%)	Silt (%)	Clay (%)		
TS1-1	0.6m	38.27	28.09	18.35	15.29	35.13	19.85
TS1-2	2.0m	64.82	19.86	6.85	8.46	33.79	26.06
TS4-1	2.0m	22.75	34.69	20.19	22.36	28.79	21.22
TS4-2	3.0m	67.47	6.25	4.60	4.74	24.97	22.28
TS5-1	0.6m	36.80	28.47	18.48	16.25	32.37	21.81
TS5-2	1.8m	61.63	17.54	9.15	11.67	24.51	22.65
TS7-1	1.5m	59.92	13.91	12.55	11.41	28.86	24.53
TS7-2	3.5m	62.80	14.46	10.26	9.98	35.44	21.11
TS8-1	1.5m	60.29	22.96	7.94	8.80	17.61	25.29
TS8-2	3.0m	67.62	16.08	9.04	7.26	20.22	27.2
TS9-1	0.6m	23.26	37.93	24.07	14.74	36.1	25.29
TS9-2	1.5m	74.47	18.00	4.92	2.62	16.63	27.71
TS13-1	1.0m	46.02	22.03	14.85	17.10	21.02	26.4
TS13-2	3.0m	64.43	17.56	6.01	4.22	23.9	19.72
TS14-1	1.0m	50.73	36.65	7.53	5.09	17.64	23.65
TS14-2	1.5m	77.24	15.88	5.60	1.28	16.13	19.61

As can be seen from the above test results summarized in table 4.3 above the soils became coarser while going down ward and have higher gravel content. This is due to the lower degree of weathering occurring in the research area while going down ward.

4.2 Laboratory Tests and Results

Some lateritic soils exhibit changes in physical characteristics and/or test results when tested under different conditions. The pretreatments given to lateritic materials should depend upon the actual conditions. For instance, in areas of high rainfall it may be difficult to dry soils during construction. In that case the tests should be run at the natural moisture content, and not allowed to dry in the laboratory. If the construction is during the dry season or in an area of low rainfall, then the soils should be air-dried in the laboratory. In all cases, the laboratory pretreatments should reflect actual field conditions. For this reason, lateritic soils should not be over dried prior to testing as the soils will not experience such high temperatures in the field (Lyon Associates, 1971).

In this thesis work, the index property laboratory tests were carried out in accordance with the ASTM standard testing procedures; and Lyon Associates (1971), Blight (1997) and Charman (1995) testing recommendations. Each laboratory tests which were conducted are explained in the following sections. Finally, a laboratory testing procedures which are appropriate for testing the lateritic soils of Western Ethiopia are recommended.

4.2.1 Index Property tests

Soil is a complex material. The complexity is contributed by its existence in almost innumerable varieties, by its combination of solids, liquid and gases, where in many instances the solid particles also vary in size. Furthermore, the relative quantities of solid, liquid and gases in a given soil is found to change due to any physical cause such as loading, seasonal variation and change of temperature which makes the situation further complicated (Samuel, 1989).

The engineering behavior of soils, whether formed under arctic, temperate or tropical conditions, is determined by certain physical characteristics designated as engineering properties. Since determination of the engineering properties is usually expensive, index properties, which are simpler and cheaper to evaluate but indicative of the engineering characteristics, are investigated. These properties are mainly used for identification and classification of soils (Lyon Associates, 1971).

However, studies have revealed that tropical soils are different from temperate zone soils in terms of genesis and structure. Their structures as compared to dispersed temperate zone soils have necessitated modifications to the mechanical or grading tests; the conventional pretreatment methods have considerable effect on the index properties of tropical soils. Therefore, special consideration is required during pretreatments and testing methods while testing tropical soils (Blight, 1997).

The various properties of soils which could be considered as index properties under this specific case are: moisture content, Grain size analysis, Atterberg limits, Shrinkage limit, free swell, and specific gravity.

4.2.1.1 Moisture content

4.2.1.1.1 General

In many residual soils, some moisture exists as water of hydration in the sesquioxides of iron and aluminium, which may not have an effect on the engineering performance of the soil. However, some of this moisture may be driven off by oven-drying at l05°C, the standard temperature for testing temperate region soils, to the extent that all the index tests reliant on moisture content are to be affected.

Different authors said that the conventional oven drying temperature for water content determination is too hot for certain clays and tropical soils. These soils contain loosely bound water of hydration or molecular water which can be lost at this high temperature and results a change in the soil characteristics (Bowels, 1978; Blight, 1997; Charman, 1995). This effect could be checked using different oven temperatures.

In order to address the above problem, i.e. the existence of water of hydration, in the lateritic soils of western Ethiopia, Nedjo-Jarso-Begi area, two sets of test samples were prepared from twenty nine test samples. In addition to these test samples two test samples from Addis Ababa around Entoto area were also prepared. Then, the one set of test samples were oven-dried using the standard oven drying temperature (105°C) while the other sets were oven-dried at lower drying temperature (50°C) as recommended by Blight (1997) and Charman (1995).

4.2.1.1.2 Test procedures

The moisture contents of the twenty nine test samples from Nedjo – Jarso – Begi area and two test samples from Addis Ababa around Entoto were determined in the laboratory according to ASTM D2216-92 testing procedures; and using the recommendations given in Blight (1997) and Charman (1995) for the use of appropriate drying/oven temperature. In this research work an oven drying temperatures of l05°C and 50°C (or air drying) were used to dry the test samples. For every test sample two sets of samples were prepared, i.e. two samples from each sample sources, an appropriate amount of sample were taken for the moisture content determination. One set of samples were oven-dried using a standard oven drying temperature (105°C) until successive weighing show that no further weight loss is taking place; and the other set were dried at a temperature, less than that of the standard drying temperature, of 50°C for a minimum of five days to get a constant mass in successive measurements. Finally the moisture contents for the two set of samples were calculated using the normal procedures as shown in ASTM D2216-92.

4.2.1.1.3 Test results and discussions

The two test results were compared. As recommended by A.B. Fourie in Blight (1997) moisture variation 4-6% or more indicates that there is structural water in the test sample. If this is confirmed by repeated tests then the oven drying temperatures for the subsequent programme of tests should be changed to an appropriate value or reduce the difference in moisture from the moisture content values tested conventionally.

For the test samples under investigation, the values of the moisture contents are presented and compared in Table 4.4. The natural moisture content difference using 105°C and 50°C oven temperatures is less than 4%, which indicates that the soil of Nedjo, Jarso and Begi areas do not contain a considerable amount of ‘water of hydration’ or ‘structural water’ which lead to irreversible changes on drying, hence the moisture content tests for the soils in this areas can be conducted by oven drying conventionally (105°C).

Table 4.4 Moisture contents at different temperatures

Sample Designation	Natural Moisture content (%)		Difference
	Using 50^{o}C oven temp.	Using 105^{o}C oven temp.	
TS1-1	33.74	35.13	1.39
TS1-2	30.11	33.79	3.68
TS2-1	24.70	27.23	2.53
TS2-2	17.98	21.24	3.26
TS3-1	22.99	26.63	3.64
TS3-2	27.52	31.36	3.84
TS4-1	24.97	28.79	3.82
TS4-2	21.87	24.97	3.10
TS5-1	31.10	32.37	1.27
TS5-2	23.16	24.51	1.35
TS5-3	27.99	30.19	2.20
TS6-1	12.69	16.29	3.60
TS6-2	16.51	20.44	3.93
TS7-1	25.12	28.86	3.74
TS7-2	31.89	35.44	3.55
TS8-1	15.80	17.61	1.81
TS8-2	16.68	20.22	3.54
TS9-1	33.07	36.10	3.03
TS9-2	12.86	16.63	3.77
TS10-1	15.12	19.06	3.94
TS11-1	32.50	35.92	3.42
TS12-1	13.27	17.05	3.78
TS13-1	17.42	21.02	3.60
TS13-2	19.94	23.90	3.96
TS14-1	15.32	17.64	2.32
TS14-2	13.97	16.13	2.16
TS14-3	14.62	16.75	2.13
TS15-1	21.32	23.61	2.29
TS16-1	15.89	18.37	2.48
Sample-A (from A.A.)	*29.19*	*30.4*	*1.21*
Sample-B (from A.A.)	*21.81*	*22.91*	*1.10*

4.2.1.2 Grain size analysis

4.2.1.2.1 General

The size of the particles that constitute soils may vary from that of boulders to clay. Grain size analysis is an attempt to determine the relative proportions of different grain sizes which make up a soil mass.

The usual grain size testing and analysis (temperate zone soils) consists of first drying the soil sample brought from the test pit and then pulverizing it before letting run through a nest of sieves. The soil passing the No. 10 sieve (fine soils) was separated by hydrometer analysis. Then, the result obtained was expressed by a plot of percent finer (passing) by weight against size of soil particles in millimeters on a log scale. As discussed in Section 2.2.1.1 one of these conventions is the assumption of a constant specific gravity for the soil particles; when determined by measurement this value is usually an average over the full range of particle sizes; however, for some laterites, whose coarse fraction is iron-rich and whose fine fraction is kaolinite, this convention may be misleading. The coarse fraction usually has a specific gravity of between 3.0 and 3.5 (but sometimes very much higher), while the specific gravity of the finer material is about 2.7. The particle-size distribution curve is based on proportions by mass retained on successive sieves, and only represents a particular packing arrangement for a soil of constant specific gravity. Given this discrepancy in specific gravity, a conventionally test applied to laterities would overestimate the volume content of coarser particles and exaggerate any gap-grading in the material, and would not represent the true packing and mechanical stability of the material as a whole.

It is important therefore, when judging grading analyses to inspect the material assess its composition and decide if separate specific gravity determinations of the fine and coarse fractions should be made. If the specific gravities are significantly different, the grading should be calculated by modified mass proportions as well as by conventional mass proportions (Charman, 1995). An example of this modification of grading analysis and the resulting grading curves are presented in Table 4.5 and Figure 4.2 respectively. This procedure will give a clearer indication of the potential mechanical stability of the compacted aggregate. If gradings are presented on the basis of modified mass proportions, they must be clearly identified as such.

It is also discussed, in Section 2.2.1.1, that relatively weak coarse particles may also cause problems in grading analysis as they become finer during sample preparation technique i.e. during pulverization. For the analysis to represent the source material, the sample preparation and test procedures should not fracture the coarse particles. It is equally important that the fines adhering to the coarse particles should be removed. It is therefore recommended by different authors that such soil particles should be soaked until the coating material is fully softened; that only the wet sieving procedure be used; and that a ‘closed system’ of washing be maintained so that no material is lost in the process. Any tendency for the coarse particles to fracture should be recorded on the test reports (Charman, 1995; Lyon Associates, 1971).

Generally the assessment of a soil or aggregate for highway pavement use would not require sedimentation analysis of the fraction smaller than 75 microns in size. When sedimentation analyses are made, however, it should be remembered that the techniques of dispersion, which have not been standardized, can affect the results. The dispersing agent and procedure should therefore be reported with the test result (Charman, 1995).

Table 4.5 Modification of grading analysis by modified mass proportion for variation in specific gravity within a sample

Assuming constant specific gravity (S.G.)						
Sieve size (mm)	Cumulative mass percentage passing each sieve	Therefore, mass retained on each sieve in a 100g sample	But visual inspection and separate S.G. determinations reveal that	Therefore, mass retained on each sieve re-proportioned for variation in S.G.	Equivalent mass retained on each sieve for 100g sample	Therefore, Cumulative mass percentage passing each sieve
50	*100*	0	S.G. (fraction > 5mm) = 3.5	0.00	0.00	*100.00*
31.5	*85*	15	S.G. (fraction < 5mm) = 2.7	11.57	13.48	*86.52*
20	*70*	15	Therefore, mass retained on each sieve larger than 5 mm should be factored by	11.57	13.48	*73.04*
10	*50*	20		15.43	17.98	*55.06*
5	*38*	12	ratio = $\frac{2.7}{3.5}$ 0.77	9.26	10.79	*44.27*
2	*30*	8		8.00	9.32	*34.95*
0.5	*25*	5		5.00	5.83	*29.13*
0.075	*20*	5		5.00	5.83	*23.30*
		20		20.00	23.30	
		100		**85.83**	**100.00**	
			OR			
				0.00	0.00	*100.00*
				15.00	13.48	*86.52*
				15.00	13.48	*73.04*
				20.00	17.98	*55.06*
			Mass retained on each sieve smaller than 5 mm should be factored by	12.00	10.79	*44.27*
				10.37	9.32	*34.95*
				6.48	5.83	*29.13*
				6.48	5.83	*23.30*
			ratio = $\frac{3.5}{2.7}$ 1.30	25.93	23.30	
				111.26	**100.00**	

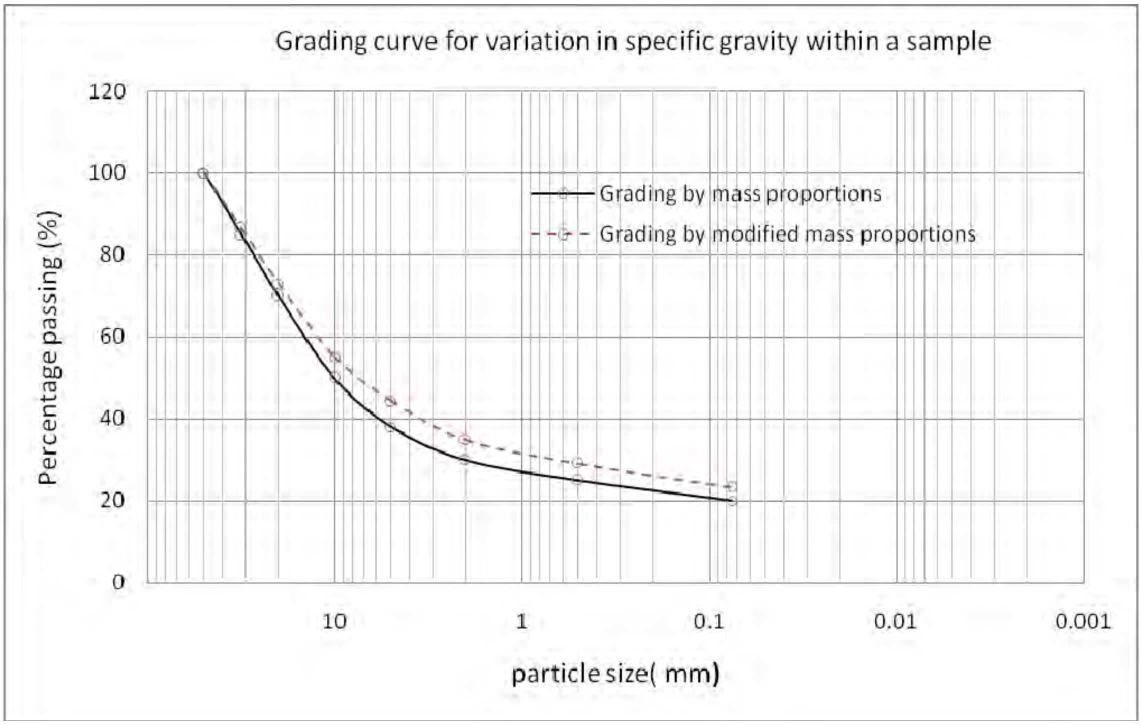

Figure 4.2 Grading curve for variation in specific gravity within a sample

4.2.1.2.2 Test procedures

Sample preparation

a) Dry preparation

The oven-dried (OD) and air-dried (AD) samples were prepared in accordance with ASTM 421-85, “Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants”. For OD test samples, Section 3 of ASTM D 421-85 was modified from air drying to oven drying.

During the sample preparation procedure the test samples as received from the field were exposed to the air at room temperature or to an oven temperature of 105^{o}C until the samples were dried thoroughly. The aggregations were broken down /pulverized/ thoroughly in the mortar with a rubber-covered pestle before they were screened through the nest of sieves. Then the ground test samples were separated in to two portions by sieving with a No.10 (2.00-mm) sieve: one portion contains only particles retained on

No.10 sieve which were used for coarse sieve analysis, while the other portion contains only particles passing No.10 (2.00-mm) sieve for hydrometer analysis.

After the coarser particles were screened through a nest of sieves and the finer particles were subjected to hydrometer using the procedures detailed in ASTM D 422-63, the results were expressed by a plot of percent finer (passing) by weight against size of soil particles in millimeters on a log scale.

Apart from the method of dry preparation of the soil samples (ASTM D 421-85) and sieve analysis tests (ASTM D 422-63), for this thesis work the air-dried soil samples were prepared by spreading the materials out in trays in the laboratory and leaving it open to the air at room temperature of about 20^{o}C for at least 15 days. An equivalently, soil sample was put in side oven at temperature of 50^{o}C for at least 5 days. Another oven-dried sample was prepared by drying the soil samples overnight at 105^{o}C oven temperatures.

b) Wet preparation

Wet preparations were used for the as-received test samples (AR) i.e. soil samples which contain all their natural moisture are tested without any form of pre-test drying. The test samples were prepared in accordance with ASTM D 2217-85, “Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants” Procedure B. This procedure provides that the samples be kept at moisture content equal to or greater than the natural moisture content.

During the sample preparation procedure the test samples as received from the field were soaked until the coating material is fully softened. It is important that the fines adhering to the coarse particles should be removed and the fracturing of weak coarse particles should be prevented (Charman, 1995; Lyon Associates, 1971). The soaked samples were washed in the manner stated in ASTM D 2217-85 Section 6.1.2 and Lyon Associates (1971), using No.10 (2.00-mm) & No.200 (0.075-mm) sieves. After washing, the materials retained on the No.10 (2.00-mm) & No.200 (0.075-mm) sieves were dried in an oven at a temperature of 105^{o}C overnight. Then the dried materials were used for the particle-size analysis using nest of sieves. The dry weights used in the computations for the gradation were calculated by using the wet weight and moisture contents of the test samples before sieving as recommended in Lyon Associates (1971). In addition to this, the hydrometer analysis was used in the determination of particle-sizes less than sieve No. 200 (0.075-mm) in accordance with the procedures stated in ASTM D 422-63 keeping the soil sample in moist condition.

4.2.1.2.3 Test results and discussions

The summary of particle-size analysis test results of all test samples under investigation for the different testing conditions /pretreatments/ is presented in Table 4.6. The particle-size analysis test results were analyzed to understand the effects of different testing procedures, which use different pretreatment conditions (i.e. AR, AD & OD). In addition to this the variations of grading curves for variation of sample location /depth/ was analyzed. The effect of using separate specific gravities on grading analysis was also inspected while using the separate specific gravity for the fine and coarse fractions of the test samples. The corresponding particle-size distribution /grading/ curves are shown in Figure. 4.3 to 4.7 (the particle-size distribution curves presented here are only the typical ones. The grading curves of most test samples under investigation, for variations in pretreatment conditions /testing procedures/, for variations in specific gravity within a sample, for variations in sample location, and range of gradation curves are presented in Appendix-B).

Effect of pretreatments /testing procedures/

Test samples were tested for the three pretreatment conditions namely Oven-dried (OD), air-dried (AD) and as-received (AR) to investigate the effect of different pretreatments on particle-size distribution /grading/ curves of the soils in the research areas. The test results are shown in Table 4.6 & Figures 4.3.

From the grading curves presented in Appendix-B and percentage of particle sizes shown in Table 4.6 one can observe that in the AD and OD conditions of pretreatments and testing procedures resulted to increase the finer particles of the soil samples while the coarser particles are decreased in percentage. Generally, the particle-size distributions of some lateritic soils change as a result of hydration reaction when soils are dried specially at high temperatures. The test result for dry preparation (AD & OD) of samples is expected to decrease percentage of the finer fraction (clay); on the other hand, test results of samples tested using wet preparation (AR) condition are expected to cause the reverse as compared to effect of drying, i.e. to increase percentage of finer fraction. This is due to the fact that the fines adhering to the coarse particles could be removed during washing. In addition to the effects of temperature, the particle-size distribution of some lateritic soils can be changed if the coarse particles are fractured due to the method of sample preparation and test procedures.

In this thesis work, three different pretreatment conditions (AR, AD & OD) were used for the particle-size analysis of soil under investigation. That is AD and OD samples were used for dry preparation of samples while the AR samples were used for wet preparation of samples. As one can see from the test results, that the dry sample preparation techniques and dry testing procedures were used, resulted in increasing the fraction of sand (in AD & OD samples), silt (in AD samples) and clay (in AD samples); however, the percentage of gravels is reduced in majority of soil samples during the dry preparation and testing techniques.

From the test results, one can also see that the percentage of silts and clays is increased in dry preparation for the case of air-dried samples; however, for the oven-dried samples it is nearly the same, i.e. the oven-dried pretreatment condition resulted in small difference for the finer portion of gradation (i.e. for silts and clays). This may be the fact that when lateritic soils are oven-dried there is mineralogy alteration and/or development of larger capillary forces between particles; hence, the degree of bondage for fine particles become increased as a result of the cementation of sesquioxides; and the cementation will no longer be disintegrated by manipulation /pulverization/.

However, from the test results one can also see that the dry sample preparation and testing procedure causes to decrease the percentage of coarser particles. This is because the coarser particles became highly fractured during the pulverization process.

It is therefore recommended that the wet sieving method /testing procedures/ should be used for the soil samples under investigation. The soils are sensitive to manipulation /pulverization/. The soils should not be prepared using the dry preparation method as discussed above rather they should be prepared using the wet preparation method, i.e. the soil should be soaked until the coating material is fully softened and the wet sieving procedures should be practiced.

Effect of Specific gravity Variation

The assumption of constant specific gravity for the soil particles while carrying out particle-size distribution analysis assumes one average value over the full range of particle-sizes. For some laterites, whose coarse fraction is iron-rich and whose fine fraction is kaolinite, this convention may be misleading as it would overestimate the volume content of coarser particles and exaggerate any gap-grading in the material, and would not represent the true packing and mechanical stability of the material as a whole (Charman, 1995).

In order to address this problem separate specific gravity tests were conducted for coarser and finer particles. The specific gravity of the coarser fractions was determined according to the methods recommended by Lyon Associates (1971) on air dried samples (as an alternative ASTM C 127 can be consulted or used). Once the separate specific gravities were determined, the grading was calculated by modified mass proportions as well as by mass proportions.

As can be seen from the grading curves shown in Figures 4.4 to 4.5 and in Appendix-B (where the grading curves of few test samples under investigation for variation in specific gravity within a sample is attached), the grading curves using mass and volume proportions are not varied significantly, especially for test samples tested under wet testing method (i.e. AR pretreatment condition). For the case of dry prepared samples (AD & OD samples) there is a slight difference in the grading curves, even if the OD samples have higher difference than AD samples. This can be seen in Appendix-B for test samples TS1-2, TS67-1, TS8-2 and TS16-1. Generally all soils under investigation do have nearly identical grading curves, i.e. the grading curves using mass proportion and the modified grading curves using modified mass proportion are nearly the same. Hence, for the soils under investigation one can say that the need of modifying the grading curves using modified mass proportion is not as such important especially when wet sieving method is used.

Effect of sample location /sampling depth/

Residual soils formed at the same profile and locations show nearly similar characteristics due to their mode of weathering, deposition and soil forming factors to which they are exposed. These soils vary from a highly weathered soil at the top to a strong un-weathered rock or intact rock at the bottom. From the test results summarized in Table 4.6 one can see that, the soils under investigation showed an increase in percentage of coarse particles when soils are sampled with increasing depth. This can also be seen from Figures 4.6 & 4.7 for test samples TS5 (TP5-1, TS5-2 and TS5-3) and TS14 (TP14-1, TS14-2 and TS14-3) respectively that the grading curves showed that the soil samples become increasing in the coarser fraction while increasing the sampling depth.

Hence, one can see from the test results shown in Table 4.6 and gradation curves attached in Appendix-B that the soils under investigation showed increasing of the coarser fractions while soils were sampled from top to an increased depth. This is therefore, from the actual site condition and the laboratory results; the soil of western Ethiopia shows a decreased in fine fractions and/or an increase in coarse sized particles in going down along the profile /depth/. This is also observed by previous researchers (Zelalem, 2005; Wakuma, 2007; Dibisa, 2008).

Range of gradation curves

The range of grading curves for the soils under investigation is relatively wide. This is due to the fact that for residual soils the sequence of materials ranging from a true soil at the top and to softer rocks at the bottom which is highly depending on the degree of weathering. The range of grading curves for the soil samples under investigation in this work is as shown in Figure 4.8 for various pretreatment conditions (range of grading curves are also attached in Appendix-B for each pretreatments separately).

Table 4.6 Percentage amount of particle-sizes at different pretreatments and depths

S.N.	Sample Location		Sample Designation	Pretreatment conditions	Percentage amount of particle-sizes			
	Station, Offset	Depth			Gravel	Sand	Silt	Clay
1	10+880, 1.5km RHS	0.6m	TS1-1	AR	38.27	28.09	18.35	15.29
				AD	31.02	27.52	17.16	24.31
				OD	37.74	42.45	8.55	11.26
2	10+880, 1.5km RHS	2.0m	TS1-2	AR	64.82	19.86	6.85	8.46
				AD	57.98	21.60	10.10	10.33
				OD	57.95	21.86	11.37	8.82
3	16+280, 20m RHS	1.5m	TS2-1	AR	54.67	31.33	5.38	8.62
				AD	43.23	36.50	11.30	8.98
				OD	47.04	35.73	8.66	8.57
4	16+280, 20m LHS	3.0m	TS2-2	AR	42.37	41.21	10.80	5.62
				AD	33.80	46.04	11.44	8.73
				OD	35.50	50.15	9.80	4.55
5	20+000, 50m RHS	0.6m	TS3-1	AR	61.59	18.01	10.16	10.23
				AD	49.37	29.88	11.21	9.54
				OD	42.17	30.72	14.19	12.93
6	20+000, 50m RHS	2.0m	TS3-2	AR	33.76	39.63	12.81	13.80
				AD	27.05	38.14	13.60	21.20
				OD	27.59	48.72	12.31	11.38
7	30+000, 20m RHS	2.0m	TS4-1	AR	22.75	34.69	20.19	22.36
				AD	20.80	48.94	15.08	15.18
				OD	22.28	39.74	22.51	15.47
8	30+000, 20m RHS	3.0m	TS4-2	AR	84.40	6.25	4.60	4.74
				AD	68.73	12.10	8.81	10.35
				OD	70.54	14.47	8.62	6.37
9	35+980, 120m RHS	0.6m	TS5-1	AR	36.80	28.47	18.48	16.25
				AD	30.62	33.43	16.69	19.26
				OD	36.23	31.44	17.16	15.17
10	35+980, 120m RHS	1.8m	TS5-2	AR	61.63	17.54	9.15	11.67
				AD	64.82	18.33	9.44	7.42
				OD	75.15	15.17	4.83	4.85
11	35+980, 120m RHS	2.5m	TS5-3	AR	65.64	18.92	6.46	8.97
				AD	48.14	28.15	12.41	11.31
				OD	58.11	25.67	7.12	9.10
12	44+080, 40m LHS	1.0m	TS6-1	AR	74.81	14.91	6.07	4.22
				AD	64.21	16.69	15.06	4.04
				OD	65.66	18.85	9.48	6.01
13	44+080, 40m LHS	2.0m	TS6-2	AR	49.83	32.22	12.25	5.70
				AD	55.76	22.89	8.61	12.75
				OD	70.38	15.55	4.53	9.54
14	49+100, 20m LHS	1.5m	TS7-1	AR	62.12	13.91	12.55	11.41
				AD	51.39	21.52	16.66	10.43
				OD	55.33	20.35	11.19	13.13
15	49+100, 20m RHS	3.5m	TS7-2	AR	65.30	14.46	10.26	9.98
				AD	60.44	17.87	10.57	11.12
				OD	58.90	22.43	9.11	9.56
16	53+000, 40m RHS[3]	1.5m	TS8-1	AR	60.29	22.96	7.94	8.80
				AD	55.73	26.16	9.05	9.05
				OD	60.90	24.45	4.99	9.66
17	53+000, 40m RHS	3.0m	TS8-2	AR	67.62	16.08	9.04	7.26
				AD	60.73	20.23	11.02	8.02
				OD	57.89	27.80	7.28	7.04

Percentage amount of particle-sizes at different pretreatments and depths (continued)

S.N.	**Sample Location**		**Sample Designation**	**Pretreatment conditions**	**Percentage amount of particle-sizes**			
	Station, Offset	**Depth**			**Gravel**	**Sand**	**Silt**	**Clay**
18	58+000, 50m LHS[4]	0.6m	TS9-1	AR	23.26	37.93	24.07	14.74
				AD	13.93	43.67	28.62	13.77
				OD	16.67	30.96	10.27	42.09
19	58+100, 50m LHS	1.5m	TS9-2	AR	74.47	18.00	4.92	2.62
				AD	62.67	23.92	8.21	5.20
				OD	60.24	23.54	6.03	10.19
20	58+200, 200m LHS	0.6-1.5m	TS10-1	AR	59.58	20.79	10.46	9.16
				AD	52.67	25.15	11.46	10.72
				OD	53.25	27.49	10.84	8.41
21	58+200, 250m LHS	1.0-2.0m	TS11-1	AR	47.85	18.90	16.44	16.80
				AD	30.27	28.55	28.87	12.31
				OD	32.96	31.54	21.77	13.73
22	70+040, 300m [3]RHS	1.0-2.0m	TS12-1	AR	55.98	26.94	8.05	9.02
				AD	42.15	30.60	14.28	12.97
				OD	46.24	35.87	8.39	9.51
23	70+840, 20m [4]LHS	1.0m	TS13-1	AR	46.02	22.03	14.85	17.10
				AD	37.52	34.58	18.65	9.25
				OD	38.07	38.83	18.20	4.90
24	70+840, 20m LHS	3.0m	TS13-2	AR	72.21	17.56	6.01	4.22
				AD	61.36	19.67	11.24	7.74
				OD	59.33	22.25	13.57	4.84
25	74+300, 30m RHS	1.0m	TS14-1	AR	50.73	36.65	7.53	5.09
				AD	58.76	23.62	7.90	9.71
				OD	59.33	26.73	7.36	6.58
26	74+300, 30m RHS	1.5m	TS14-2	AR	77.24	15.88	5.60	1.28
				AD	73.12	15.04	7.00	4.85
				OD	73.80	17.01	4.50	4.69
27	74+300, 30m RHS	3.0m	TS14-3	AR	84.81	8.11	2.83	4.24
				AD	77.06	16.01	3.98	2.94
				OD	73.37	19.21	4.75	2.67
28	84+200, 200m RHS	1.0-2.0m	TS15-1	AR	57.33	22.29	9.68	10.69
				AD	49.86	26.32	13.11	10.71
				OD	55.44	23.37	10.80	10.39
29	84+200, 200m RHS	1.0m	TS16-1	AR	69.58	18.91	5.58	5.93
				AD	51.62	28.65	9.40	10.33
				OD	51.16	27.38	10.11	11.35

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[3] RHS refers Right hand side from road center line

[4] LHS refers Left hand side from road center line

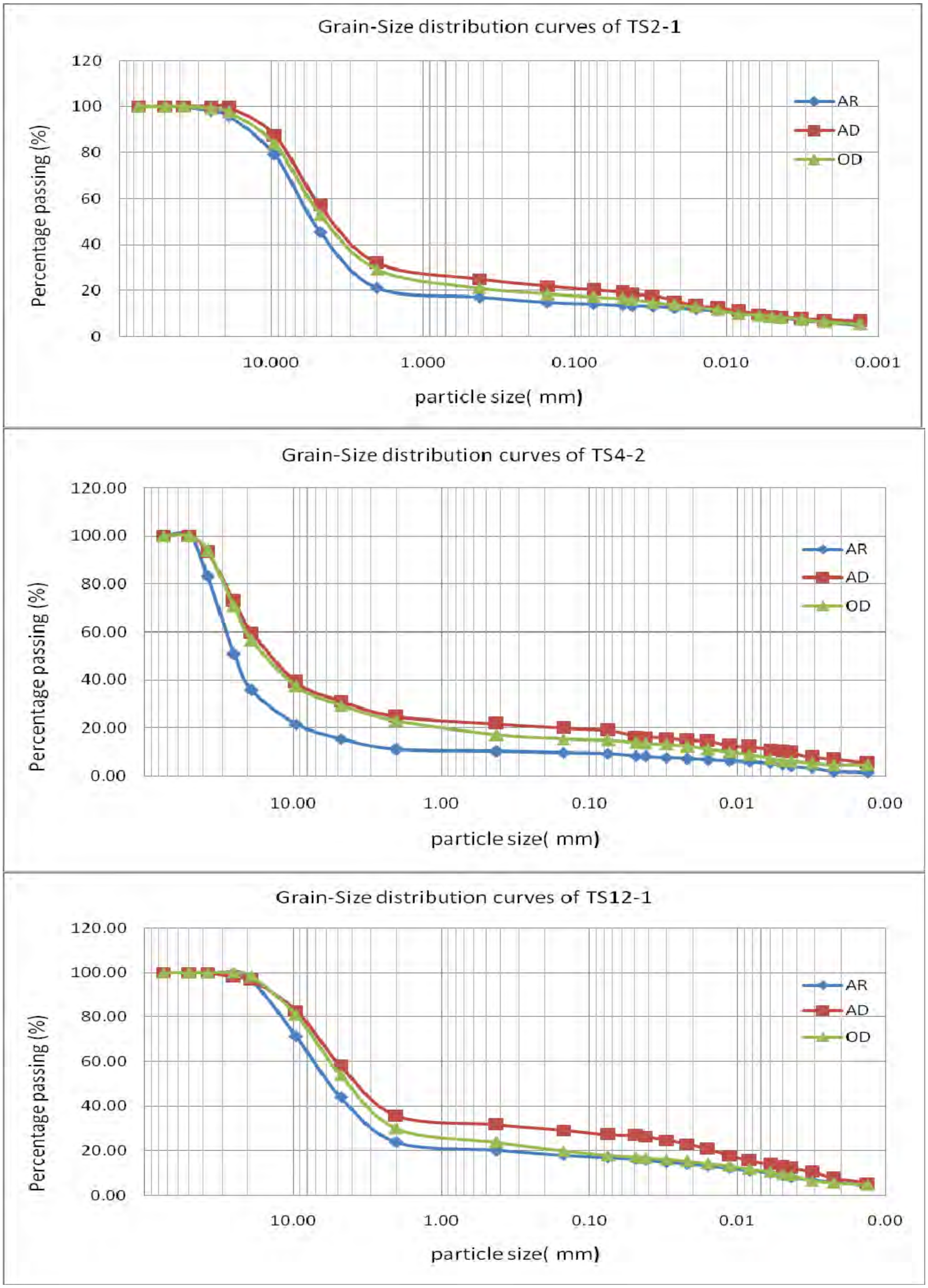


Figure 4.3 Gradation curves for variation in sample pretreatments /testing procedures/ (TS2-1, TS4-2 & TS12-1)

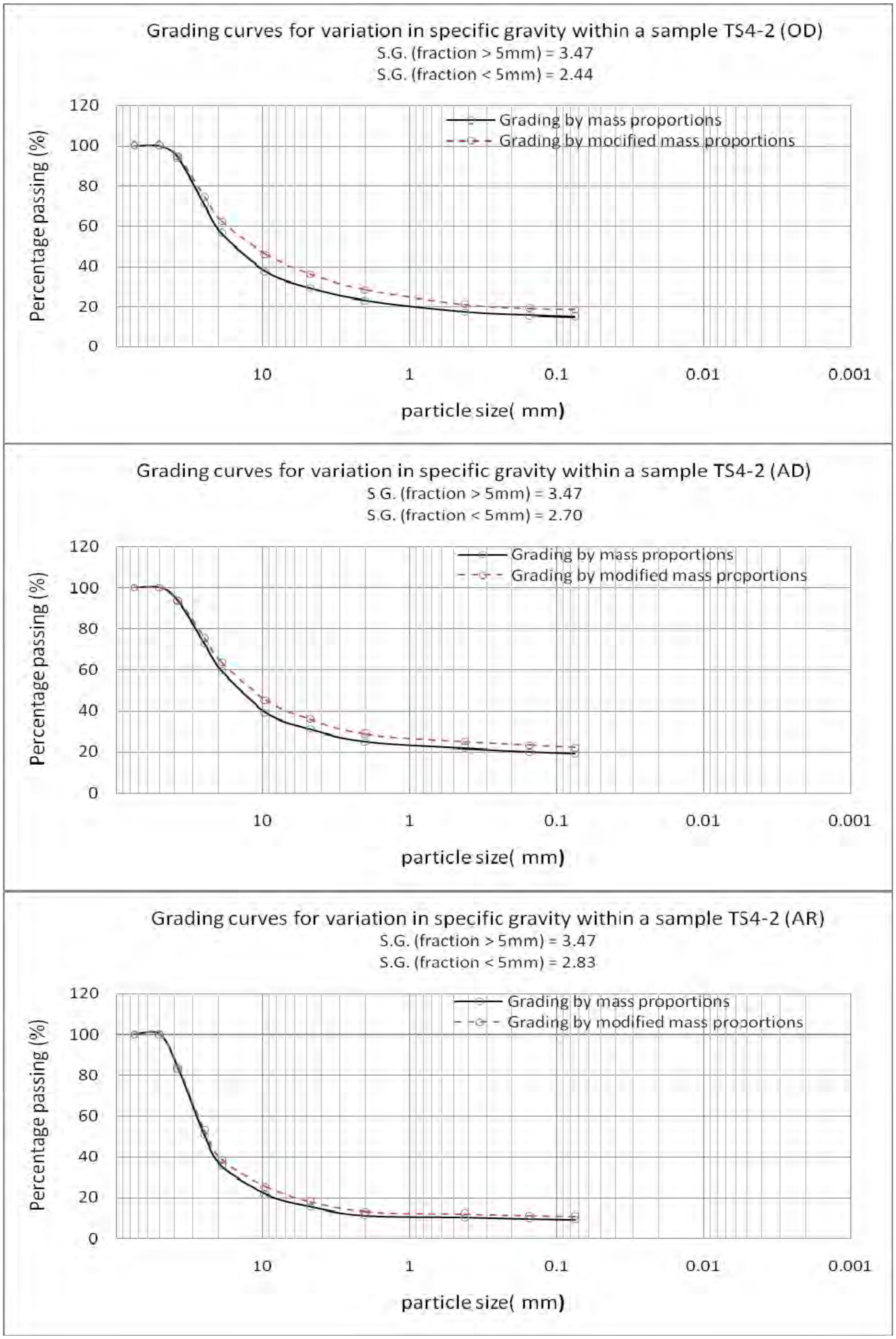


Figure 4.4 Gradation curves for variation in specific gravity and sample pretreatments within a sample (TS4-2)

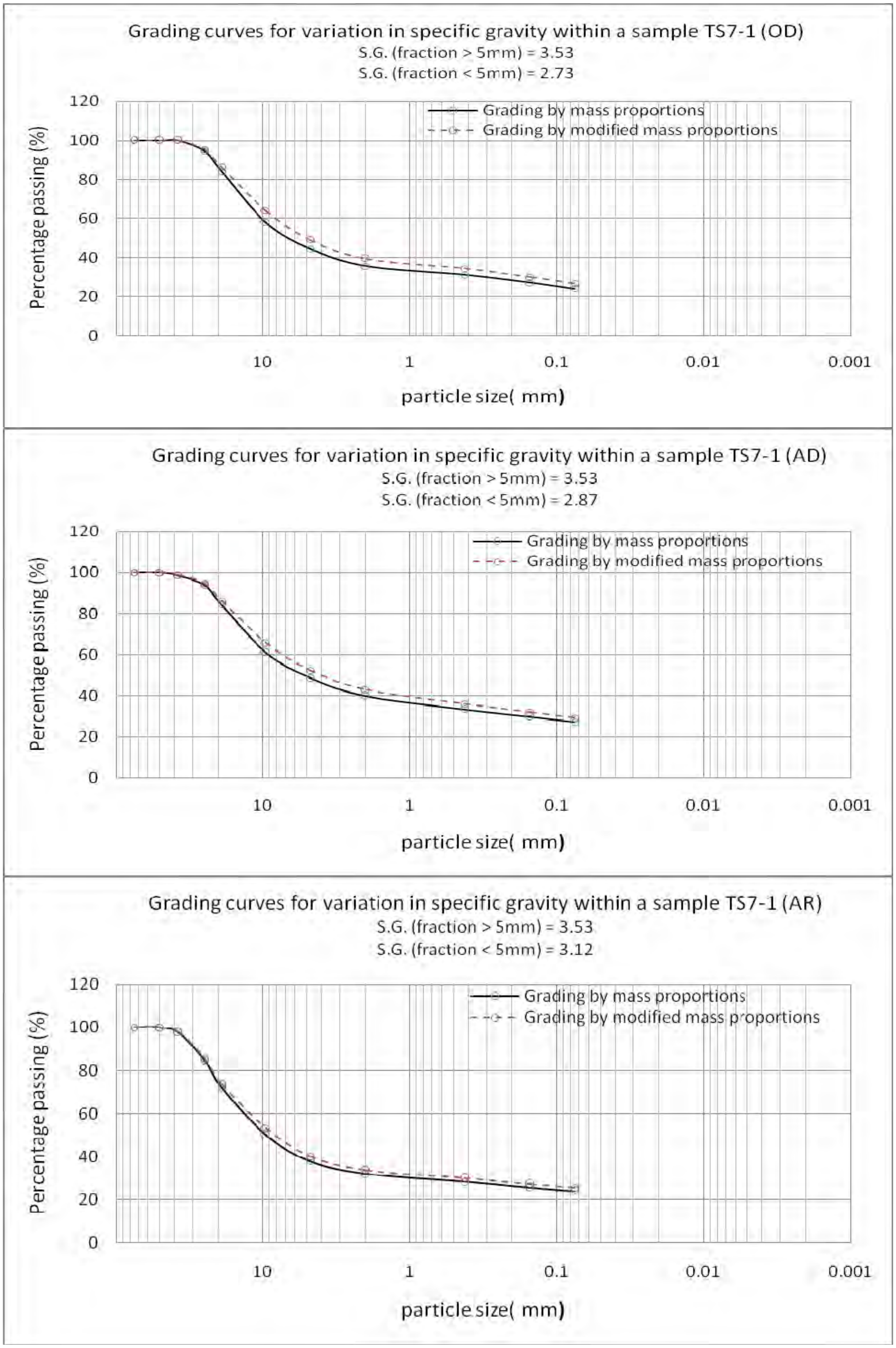


Figure 4.5 Gradation curves for variation in specific gravity and sample pretreatments within a sample (TS7-1)

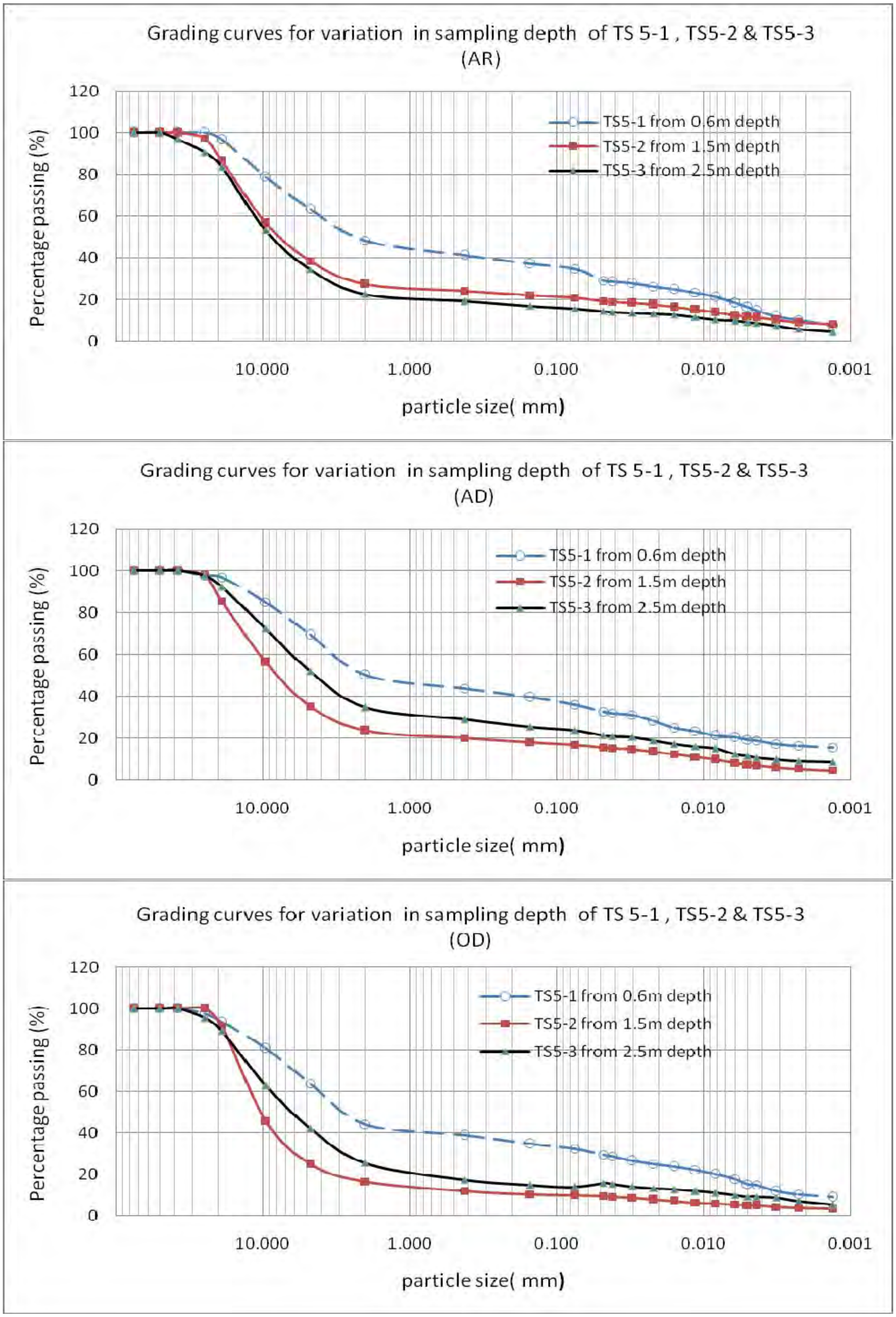


Figure 4.6 Gradation curves for variation in sample locations /depths/
(TS5-1, TS5-2 & TS5-3)

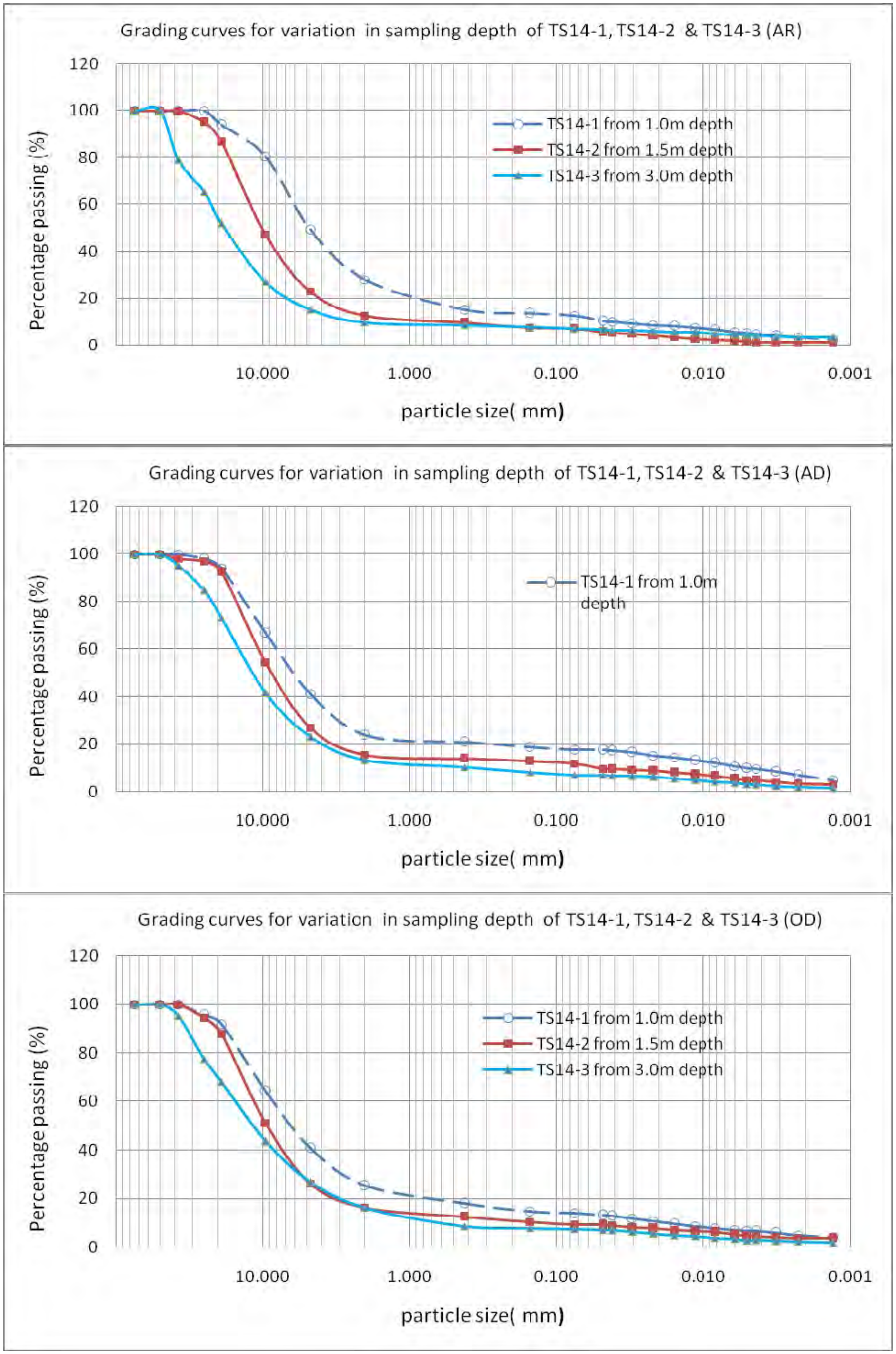


Figure 4.7 Gradation curves for variation in sample locations /depths/
(TS14-1, TS14-2 & TS14-3)

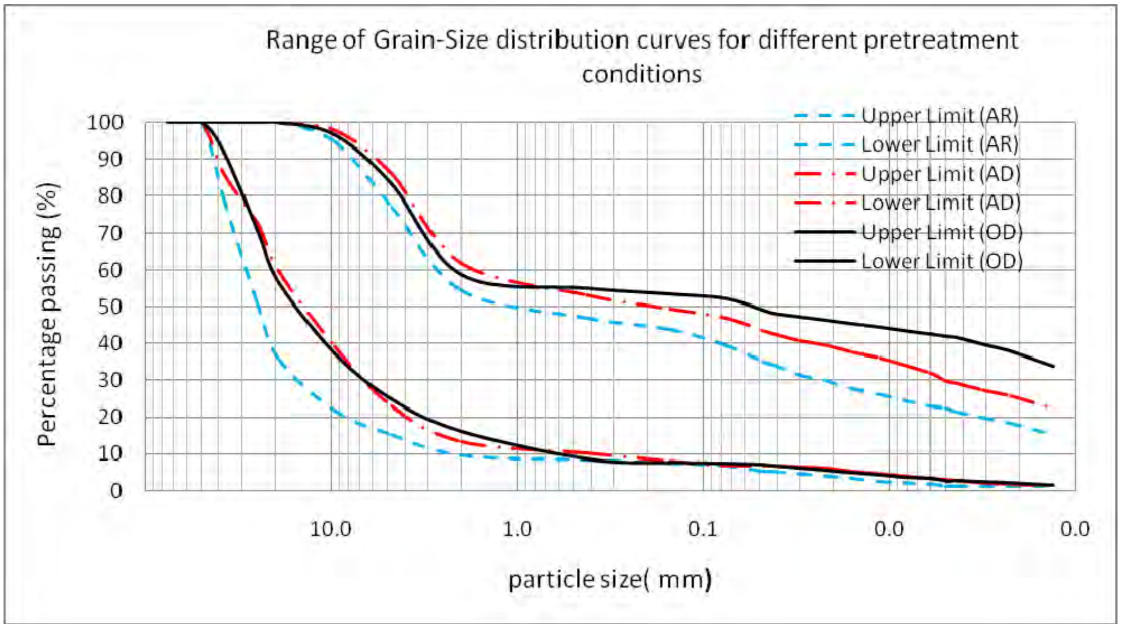


Figure 4.8 Ranges of grain-size distribution /grading/ curves for different pretreatment conditions /testing procedures/

4.2.1.3 Atterberg limits

4.2.1.3.1 General

Lateritic soils are susceptible to breakdown with manipulation; hence test procedures for Atterberg limits should be more strictly controlled. Excessive manipulation during testing leads to disaggregation of clay-size particles that produce fines which result in higher liquid limit values. In order to control these problems the mixing times shall be kept to a minimum, generally about 5 minutes for each point in the plasticity tests (Lyon Associates, 1971; Blight, 1997).

As discussed in section 2.5.2.1 some lateritic soils show changes in physical properties when tested under different drying temperatures. It is well-known that oven-drying, and even air-drying, affects the properties of these soils, though this effect is usually small for transported soils. Because of their origin and slow in situ decomposition in a largely anaerobic environment, lateritic soils are particularly prone to changes in properties caused by drying and exposure to air. Drying can cause partial or complete dehydration of the clay minerals and can change them and their properties irreversibly. Even air-drying at an ambient temperature can cause changes that cannot be reversed by re-wetting, even if the re-wetted soil is allowed to mature for long periods (Blight, 1997).

In order to address the effect of temperature, tests were carried out on air-dried, oven-dried and as-received test samples. In addition to these, the effect of disaggregation of clay size particles up on manipulation during Atterberg limit testing were also checked by conducting different testing procedures on air-dried, oven-dried and as-received test samples as mentioned in section 2.5.4. The Atterberg limit tests were carried out on all soil samples according to the procedures and recommendations mentioned in Lyon Associates (1971), ASTM (2004), Charman (1995) and Blight (1997). For the soils under investigation, the test results are summarized in Table 4.8. The mixing time and pre-treatment conditions are also shown in the same Table.

4.2.1.3.2 Test procedures

For the determination of the Atterberg limit values, air-dried and oven-dried soil samples were tested following the procedures given in ASTM D 421-85, D 2217-85 and D 4318-95 except for some variations in sample preparation. The air-dried soil samples were prepared by spreading the material out in trays in the laboratory and leaving it open to the air for at least 15 days or equivalently put inside oven at a temperature of 50^{o}C for at least 5 days until they were dried thoroughly. The room temperature was about 20^{o}C. The oven-dried samples were prepared by drying the soils overnight at 105^{o}C oven temperature. Wet sample preparations were also carried out on as-received soil samples /samples which were kept at their natural moisture content prior to preparation/ according to ASTM D 2217-85 procedure B. In the case of drily prepared test samples, i.e. for air and oven-dried test samples, portion of the dried soil samples passing No. 40 (0.425mm) sieve were kept wet for a period of 24 hrs for moisture content equilibration before carrying out Atterberg limit tests; however, in the case of wetly prepared soil samples the moist portion, i.e. wet soil portion which was passed while it was washed on No. 40 (0.425mm) sieve were kept drying, i.e. reducing the moisture content, until the mass reaches a putty-like consistency (such as 15-25 drops of the cup in the liquid limit test). Finally, Atterberg limit tests were carried out by reducing the moisture content (from wet to dry point) (Lyon Associates, 1971).

4.2.1.3.3 Test results and discussions

Generally, if the liquid limit values of the specimens for mixing times of 5 minutes (LL 5min) and 30 minutes (LL 30min) do have a difference “>5%” it can be said that the test result indicates that aggregation of clay size particles are broken down up on manipulation (Blight, 1997).

In this research’s laboratory test results in Table 4.7 and 4.8 one can see that the soils in these areas are sensitive to handling and disturbance /manipulation/. That is the more the soil is disturbed, the finer the aggregates become in grading and the higher the Atterberg limit. As the greater duration of mixing (i.e., the greater the energy applied to the soil prior to testing) the larger the resulting liquid limit, and to a lesser extent, the larger the plasticity index. This result is in agreement with compiled notes of Fourie A.B in Blight (1997) and previous researchers (Zelalem, 2005; Wakuma, 2007).

Effect of mixing times on Atterberg Limits

In general it is believed that, the greater the energy applied and longer mixing time will result in more extensive breaking down of cemented bonds between clay clusters and within peds and thus the formation of greater portions of fine particles. This effect can be seen on the extent to which liquid limit value increases for an increment of mixing time.

Excessive manipulation during testing leads to crumbling of the soil structure and disaggregating; these effects produce fines which in turn result in higher liquid limit values. Hence, the mixing time should be kept to a minimum, generally about 5 minutes for each point in the plasticity tests (Lyon Associates, 1971).

To address this problem, liquid limit and plastic limits of the twenty nine samples which were collected from the research areas, Nedjo-Jarso-Begi, and additional two samples were collected from Addis Ababa, around “Entoto”, were checked by conducting different testing procedures on air-dried, oven-dried and as-received test samples as discussed previously. The difference in the liquid limit for 5 minutes and 30 minutes mixing times is shown together with the drying conditions in Table 4.7 & 4.8. ASTM D 421-85 and D 4318-95 test procedures were adopted for AD and OD test samples while ASTM D 2217-85 procedure B and ASTM D 4318-95, with a modification of testing procedure when carrying out the liquid limit tests. This is done by carrying out the test from wet point to dry point while the wet soil paste getting drier and drier rather than carrying out from dry to wet points. This procedure was recommended by different authors (Lyon Associates, 1971; Blight, 1997 and Charman, 1995) while testing lateritic soils for the AR test samples conditions.

As can be seen in Table 4.7 significant differences were observed in the majority of the tests (i.e. >5%) between the liquid limit values obtained from the specimens mixed for 5min and 30min, this indicates that the cementation of the clay particles and/or laterization of the soils were broken down up on manipulation /longer mixing times. Hence, the greater duration of mixing, i.e. the greater the energy applied to the soil prior to testing, the larger the resulting liquid limit, and to a lesser extent, the larger the plasticity index. This is in agreement with compiled notes of Fourie A.B (Blight, 1997).

One can also observe from the test results shown in the tables that the soils in the research areas are disintegrated by elongation of mixing time. Thus, when Atterberg limit tests are carrying out for such soils it is recommended to limit the mixing times not more than 5 minutes; and the soils should be broken-down by soaking in water, and not by drying and grinding as can be done conventionally for temperate zone soils.

Hence, the testing programme for soils like in the research area should include the following instructions as recommended by Fourie A.B in Blight (1997). That is:

a) Limit the mixing times to not more than 5 minutes
b) Make use of fresh soil for each moisture content point in Atterberg Limit tests, as well as in compaction tests.

In addition to these, the soils should be broken-down by soaking in water, and not by drying and grinding as can be done conventionally (Lyon Associates, 1971).

The laboratory testing procedures which are appropriate for the lateritic soils found in the research areas are attached in Appendix-A.

Table 4.7 Effect of mixing time on Liquid Limit at different conditions

Sample Location		**Sample Design.**	**As-Received LL**			**Air-Dried LL**			**Oven-Dried LL**		
Station, Offset	**Depth**		**5 min.**	**30 min.**	*Diff.*	**5 min.**	**30 min.**	*Diff.*	**5 min.**	**30 min.**	*Diff.*
10+880, 1.5km RHS	0.6m	TS1-1	56	60	*4*	56	59	*3*	47	50	*3*
10+880, 1.5km RHS	2.0m	TS1-2	57	62	*5*	56	61	*5*	53	58	*5*
16+280, 20m RHS	1.5m	TS2-1	55	61	*6*	61	69	*8*	54	59	*5*
16+280, 20m LHS	3.0m	TS2-2	56	61	*6*	58	63	*5*	58	62	*4*
20+000, 50m RHS	0.6m	TS3-1	56	65	*9*	57	61	*5*	49	56	*7*
20+000, 50m RHS	2.0m	TS3-2	61	69	*7*	59	62	*4*	60	65	*5*
30+000, 20m RHS	2.0m	TS4-1	55	61	*6*	57	63	*5*	53	57	*4*
30+000, 20m RHS	3.0m	TS4-2	55	62	*8*	58	64	*6*	57	64	*7*
35+980, 120m RHS	0.6m	TS5-1	56	63	*6*	54	61	*7*	53	59	*6*
35+980, 120m RHS	1.8m	TS5-2	57	62	*5*	54	60	*6*	51	56	*5*
35+980, 120m RHS	2.5m	TS5-3	61	65	*4*	60	68	*8*	52	57	*5*
44+080, 40m LHS	1.0m	TS6-1	54	58	*4*	56	62	*6*	48	52	*4*
44+080, 40m LHS	2.0m	TS6-2	58	63	*6*	52	57	*6*	54	60	*6*
49+100, 20m LHS	1.5m	TS7-1	56	65	*9*	62	69	*6*	57	62	*5*
49+100, 20m RHS	3.5m	TS7-2	56	61	*5*	57	63	*6*	62	67	*5*
53+000, 40m RHS	1.5m	TS8-1	59	66	*7*	57	63	*6*	53	58	*5*
53+000, 40m RHS	3.0m	TS8-2	59	64	*5*	54	59	*5*	50	55	*5*
58+000, 50m LHS	0.6m	TS9-1	57	64	*7*	62	66	*4*	62	68	*6*
58+100, 50m LHS	1.5m	TS9-2	59	64	*5*	55	60	*5*	54	59	*5*
58+200, 200m LHS	0.6-1.5m	TS10-1	59	63	*5*	58	62	*5*	50	55	*6*
58+200, 250m LHS	1.0-2.0m	TS11-1	57	62	*5*	63	69	*5*	56	62	*5*
70+040, 300m RHS	1.0-2.0m	TS12-1	57	63	*6*	51	57	*6*	49	54	*5*
70+840, 20m LHS	1.0m	TS13-1	57	64	*6*	55	58	*2*	49	54	*5*
70+840, 20m LHS	3.0m	TS13-2	53	58	*5*	55	57	*2*	54	59	*4*
74+300, 30m RHS	1.0m	TS14-1	57	63	*5*	55	61	*6*	49	53	*5*
74+300, 30m RHS	1.5m	TS14-2	53	55	*3*	51	58	*7*	51	57	*6*
74+300, 30m RHS	3.0m	TS14-3	57	62	*5*	51	57	*7*	46	51	*6*
84+200, 200m RHS	1.0-2.0m	TS15-1	58	64	*6*	54	60	*5*	53	57	*4*
84+200, 200m RHS	1.0m	TS16-1	59	65	*6*	47	51	*4*	54	58	*4*
Sample from A.A. ("Entoto")	0.6m	Sample-A	58	60	*2*	51	52	*1*	50	52	*2*
Sample from A.A. ("Entoto")	1.5m	Sample-B	45	48	*3*	38	39	*1*	38	39	*1*

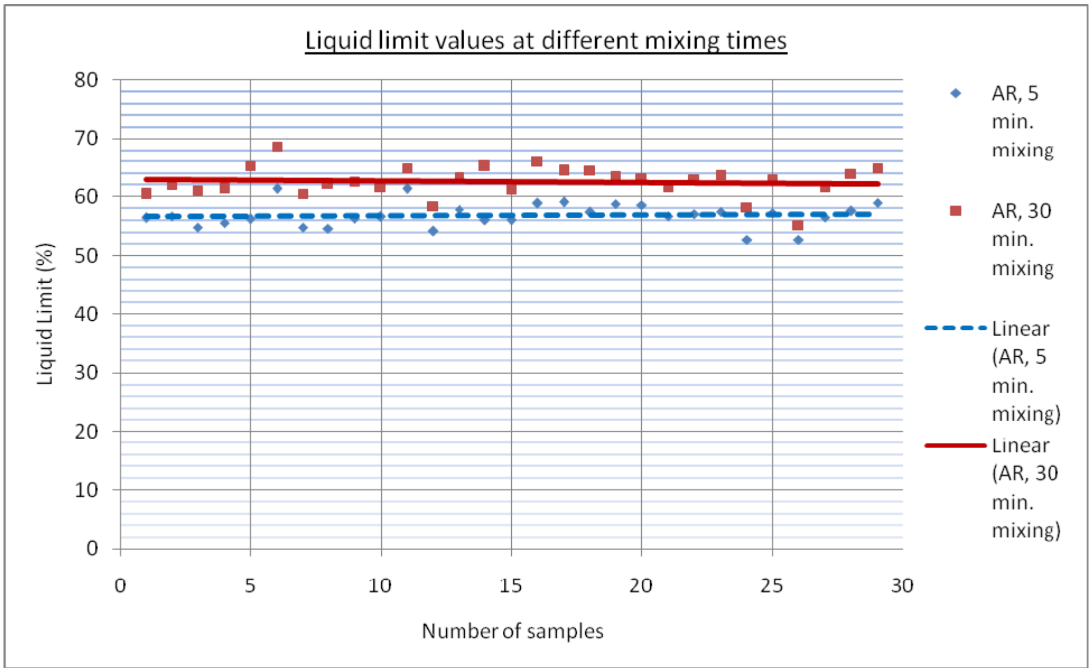


Figure 4.9 Effect of mixing times on liquid limits (AR samples)

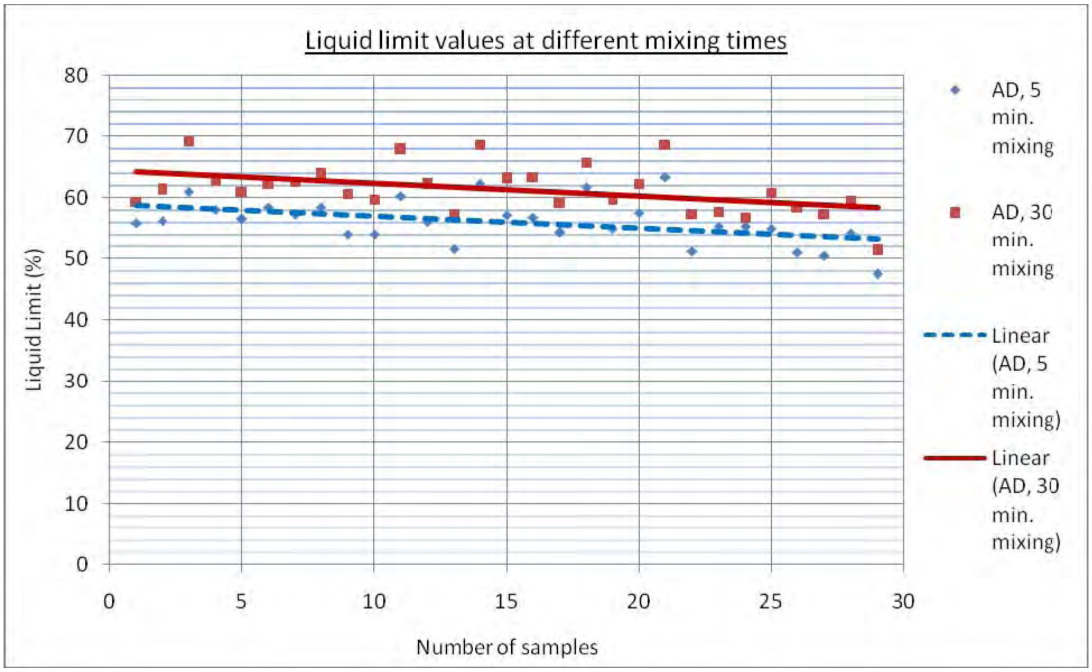


Figure 4.10 Effect of mixing times on liquid limits (AD samples)

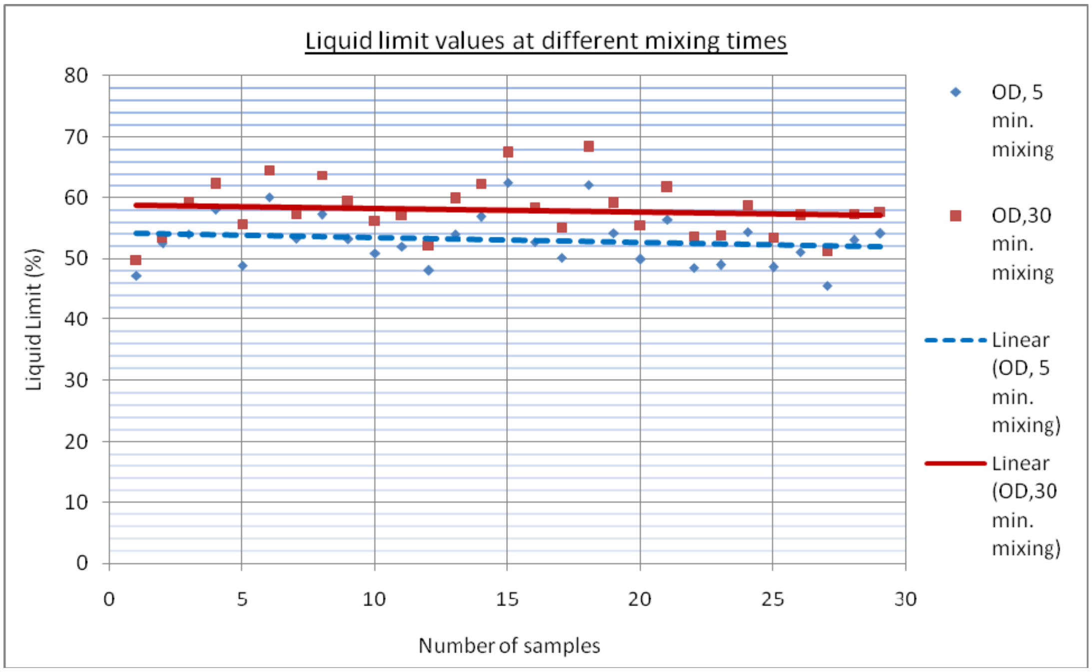


Figure 4.11 Effect of mixing times on liquid limits (OD samples)

Effects of drying temperatures on Atterberg Limits

From the Atterberg limits test results of the soils under investigation which is summarized in Table 4.8 for different pretreatments and mixing times, it can be seen that air and oven-dry pretreatments has resulted in a decrease in the liquid limit, plastic limit and to a lesser extent in the Plasticity Index.

For lateritic soils the laboratory pretreatments should reflect the actual field conditions. Hence, the test samples should not be over-dried prior to testing as the soils will not experience such high temperatures in the field (Lyon Associates, 1971; Blight, 1997).

Table 4.8 Atterberg limits at different pretreatment conditions and mixing times

Sample Location		**Sample Desig.**	**Mixing Time**	**Liquid Limits (LL)**			**Plastic Limits (PL)**			**Plastic Index (PI)**		
Station, Offset	**Depth**			**AR**	**AD**	**OD**	**AR**	**AD**	**OD**	**AR**	**AD**	**OD**
10+880, 1.5km RHS	0.6m	TS1-1	5 Min.	56	56	47	36	34	30	20	22	17
			30 Min.	60	59	50	39	35	32	22	24	18
10+880, 1.5km RHS	2.0m	TS1-2	5 Min.	57	56	53	34	31	23	23	26	29
			30 Min.	62	61	58	34	31	24	27	30	34
16+280, 20m RHS	1.5m	TS2-1	5 Min.	55	61	54	36	35	32	19	26	22
			30 Min.	61	69	59	36	36	33	25	34	26
16+280, 20m LHS	3.0m	TS2-2	5 Min.	56	58	58	33	34	33	22	24	25
			30 Min.	61	63	62	34	35	33	28	28	29
20+000, 50m RHS	0.6m	TS3-1	5 Min.	56	57	49	37	34	33	19	22	16
			30 Min.	65	61	56	38	35	33	28	27	23
20+000, 50m RHS	2.0m	TS3-2	5 Min.	61	59	60	38	35	32	24	23	28
			30 Min.	69	62	65	38	35	33	31	27	32
30+000, 20m RHS	2.0m	TS4-1	5 Min.	55	57	53	37	37	34	18	20	20
			30 Min.	61	63	57	37	38	34	24	25	23
30+000, 20m RHS	3.0m	TS4-2	5 Min.	55	58	57	34	37	32	21	21	25
			30 Min.	62	64	64	34	37	32	28	27	31
35+980, 120m RHS	0.6m	TS5-1	5 Min.	56	54	53	35	32	35	21	22	19
			30 Min.	63	61	59	36	32	35	26	28	24
35+980, 120m RHS	1.8m	TS5-2	5 Min.	57	54	51	35	35	34	21	19	17
			30 Min.	62	60	56	36	36	34	25	24	22
35+980, 120m RHS	2.5m	TS5-3	5 Min.	61	60	52	38	36	32	24	24	20
			30 Min.	65	68	57	38	37	33	27	31	24
44+080, 40m LHS	1.0m	TS6-1	5 Min.	54	56	48	37	31	34	17	25	14
			30 Min.	58	62	52	37	31	35	22	31	17
44+080, 40m LHS	2.0m	TS6-2	5 Min.	58	52	54	32	31	32	26	20	22
			30 Min.	63	57	60	32	32	33	32	25	27
49+100, 20m LHS	1.5m	TS7-1	5 Min.	56	62	57	41	39	31	15	23	25
			30 Min.	65	69	62	42	39	33	24	30	29
49+100, 20m RHS	3.5m	TS7-2	5 Min.	56	57	62	34	42	34	22	16	28
			30 Min.	61	63	67	34	42	35	27	21	33
53+000, 40m RHS	1.5m	TS8-1	5 Min.	59	57	53	32	29	34	26	28	19
			30 Min.	66	63	58	33	32	34	33	32	24
53+000, 40m RHS	3.0m	TS8-2	5 Min.	59	54	50	35	32	32	24	23	18
			30 Min.	64	59	55	36	32	32	29	27	23
58+000, 50m LHS	0.6m	TS9-1	5 Min.	57	62	62	38	34	32	20	28	30
			30 Min.	64	66	68	38	35	33	27	31	35

Atterberg limits at different pretreatment conditions and mixing times (continued)

Sample Location		**Sample Desig.**	**Mixing Time**	**Liquid Limits (LL)**			**Plastic Limits (PL)**			**Plastic Index (PI)**		
Station, Offset	**Depth**			**AR**	**AD**	**OD**	**AR**	**AD**	**OD**	**AR**	**AD**	**OD**
58+100, 50m LHS	1.5m	TS9-2	5 Min.	59	55	54	37	33	31	21	22	23
			30 Min.	64	60	59	37	33	32	26	27	27
58+200, 200m LHS	0.6-1.5m	TS10-1	5 Min.	59	58	50	35	31	33	23	26	17
			30 Min.	63	62	55	36	32	34	28	31	22
58+200, 250m LHS	1.0-2.0m	TS11-1	5 Min.	57	63	56	41	39	30	16	25	26
			30 Min.	62	69	62	41	39	31	21	30	31
70+040, 300m RHS	1.0-2.0m	TS12-1	5 Min.	57	51	49	35	38	33	22	13	15
			30 Min.	63	57	54	35	39	34	28	19	20
70+840, 20m LHS	1.0m	TS13-1	5 Min.	57	55	49	41	34	33	17	21	16
			30 Min.	64	58	54	41	35	33	23	23	21
70+840, 20m LHS	3.0m	TS13-2	5 Min.	53	55	54	35	35	33	18	20	21
			30 Min.	58	57	59	35	36	33	23	21	25
74+300, 30m RHS	1.0m	TS14-1	5 Min.	57	55	49	37	33	34	20	22	15
			30 Min.	63	61	53	37	33	33	26	27	20
74+300, 30m RHS	1.5m	TS14-2	5 Min.	53	51	51	38	36	33	15	15	18
			30 Min.	55	58	57	38	36	33	17	23	24
74+300, 30m RHS	3.0m	TS14-3	5 Min.	57	51	46	33	31	31	24	19	14
			30 Min.	62	57	51	33	32	32	29	26	19
84+200, 200m RHS	1.0-2.0m	TS15-1	5 Min.	58	54	53	39	32	33	19	22	20
			30 Min.	64	60	57	39	33	34	25	27	23
84+200, 200m RHS	1.0m	TS16-1	5 Min.	59	47	54	36	34	34	24	14	20
			30 Min.	65	51	58	36	35	36	29	16	22
(From A.A.)	0.6m	Sample -A	5 Min.	58	51	50	30	23	23	28	28	27
			30 Min.	60	52	52	30	23	23	30	29	29
(From A.A.)	1.5m	Sample -B	5 Min.	45	38	38	24	23	23	21	15	15
			30 Min.	48	39	39	24	23	23	24	16	16

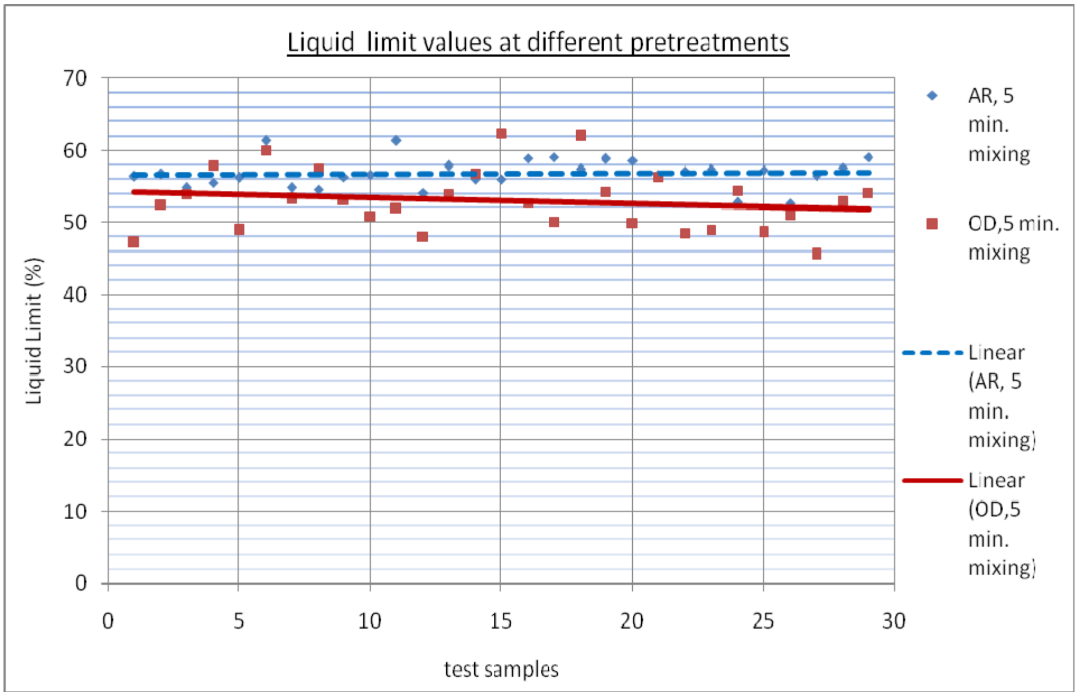


Figure 4.12 Effect of drying temperature on liquid limits (AR and OD samples)

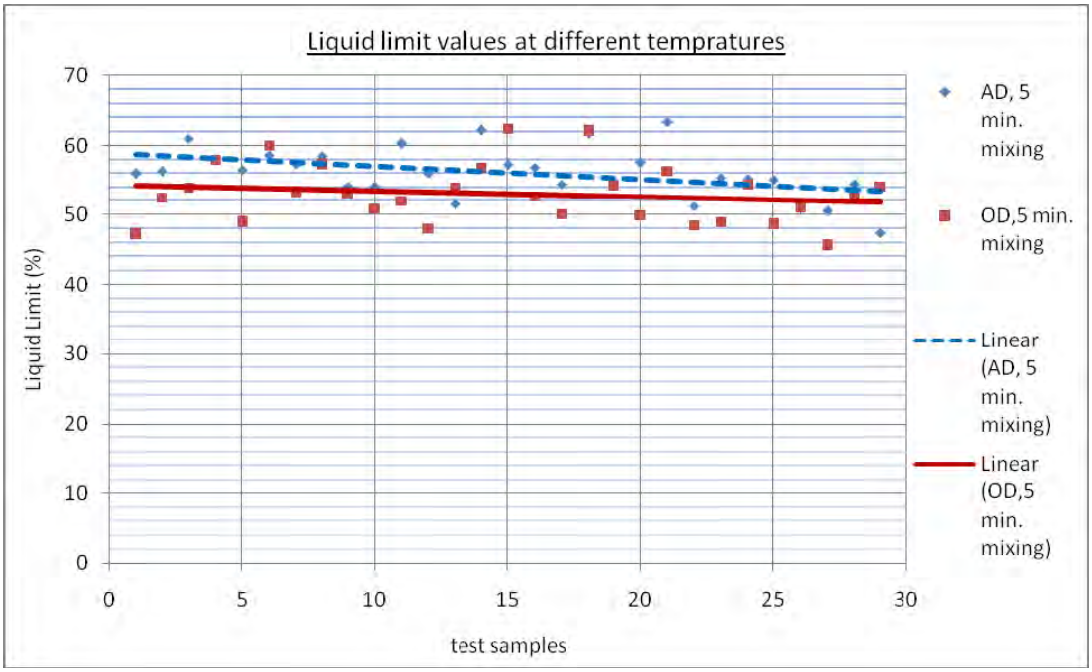


Figure 4.13 Effect of drying temperature on liquid limits (AD and OD samples)

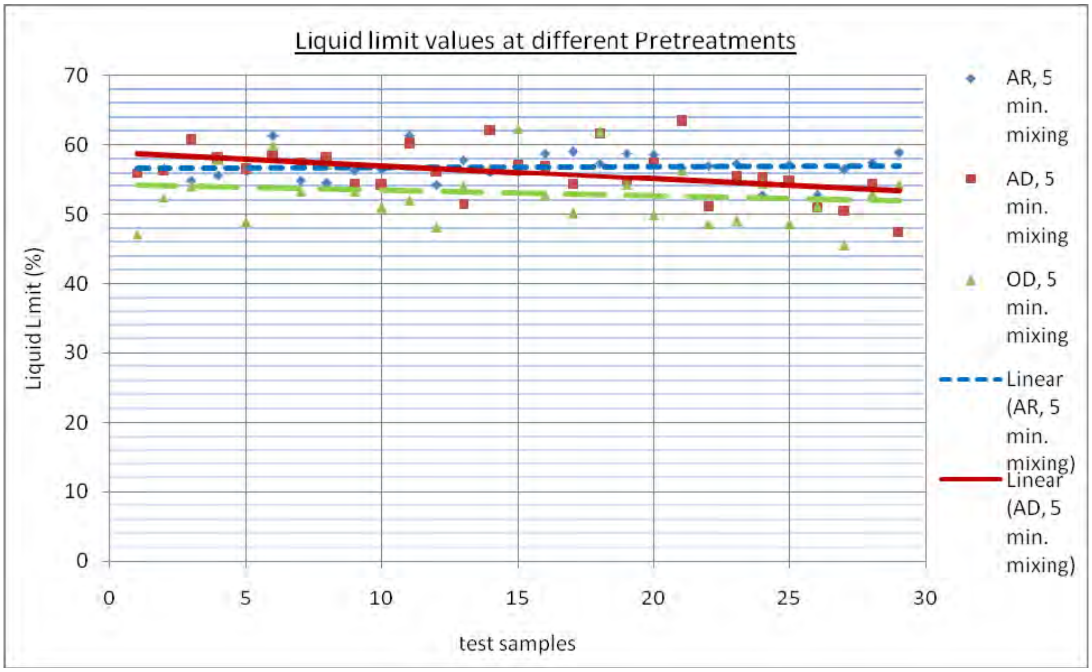


Figure 4.14 Effect of different pretreatments on liquid limits (AR, AD and OD samples)

One point Liquid Limit Test

Two methods of determining the liquid limit are provided in ASTM D 4318-95; Method A, Multipoint test as discussed in the previous section and Method B, One-point test. It is true that the multipoint liquid limit method is generally more precise than the one-point method. It is also recommended that the multipoint method be used in cases where results may be subject to dispute, or where greater precision is required.

The expression relating liquid limit (LL) to the water content (ω) of a soil sample and the number of blows (N) to close the groove in Atterberg's liquid limit test is found experimentally to be of the form:

$$LL = \omega\ (N/25)^{\tan B} \quad \text{……………………………………………………….Eq. 4.1}$$

Where: tan B is the slope of the line ω Vs N on a semi-log plot. Usually N values lie between 15-35 blows. The value for tan B reported throughout the world lie in the range 0.090-0.150 (Lyon Associates, 1971).

Lyon Associates (1971) had found that one-point liquid limit tests can be used for tropical soils effectively. Taking the value of tan B = 0.12 and limiting the number of blows to the range 20-30 gives more accurate result (Lyon Associates, 1971; ASTM, 2004).

The correlation equation, Eq. 4.1, on which the calculations of the one point method are based, may not be valid for certain soils, such as organic soils or soils from a marine environment. It is strongly recommended that the liquid limit of these soils be determined by the multipoint method (Lyon Associates, 1971; ASTM, 2004).

One-point liquid limit method has been described and investigated by a number of authors, and various formulas have been proposed. The most widely used one was developed by U.S waterway experiment station (1949) and was given above by the formula in Eq. 4.1 (Lyon Associates, 1971; ASTM, 2004).

In order to investigate the applicability of the one-point liquid limit test for the soil samples under investigation, the twenty nine samples collected from the research area and the two samples collected from Addis Ababa, were tested using ASTM D 4318-95 Method B testing procedure. For comparison the one-point liquid limit test results along with their multipoint liquid limit test results are summarized below in Table 4.9.

From the test results comparisons summarized in Table 4.9, one can see that the one point liquid limit test is acceptable for lateritic soils found in the Western Ethiopia. For number of blows 20 to 30, good comparisons can be done.

Table 4.9 Liquid limits comparison between Multipoint and One-point test methods

Sample design.	Sample pretreatment	No. of Blows	One-point LL (%)	Multi point LL (%)	Sample pretreatment	No. of Blows	One-point LL (%)	Multipoint LL (%)
TS1-1	AR, 5min. Mixing	36	73.16	56	AD, 5min. Mixing	36	77.76	56
		28	56.67			28	56.11	
		21	57.11			21	55.24	
		16	57.10			16	54.74	
TS1-2	AR, 5min. Mixing	37	78.93	57	AD, 5min. Mixing	36	78.68	56
		29	55.90			28	56.41	
		23	56.64			20	55.44	
		17	56.84			15	54.53	
TS2-1	AR, 5min. Mixing	36	72.11	55	AD, 5min. Mixing	36	80.65	61
		28	53.87			27	59.37	
		23	55.06			22	62.05	
		17	56.09			16	62.07	
TS2-2	AR, 5min. Mixing	36	75.86	56	AD, 5min. Mixing	36	76.48	58
		28	54.98			28	57.22	
		22	55.48			21	58.94	
		16	55.34			15	59.09	
TS3-1	AR, 5min. Mixing	36	78.47	56	AD, 5min. Mixing	37	74.20	57
		28	56.64			29	53.83	
		22	55.50			21	54.35	
		16	54.95			15	62.37	
TS3-2	AR, 5min. Mixing	36	84.51	61	AD, 5min. Mixing	35	77.68	59
		27	60.68			27	58.48	
		21	61.66			21	58.52	
		15	60.20			15	57.77	
TS4-1	AR, 5min. Mixing	38	79.36	55	AD, 5min. Mixing	35	75.67	57
		28	54.43			29	57.33	
		22	54.29			22	57.49	
		15	54.09			16	56.76	
TS4-2	AR, 5min. Mixing	36	72.38	55	AD, 5min. Mixing	36	80.33	58
		27	54.00			27	58.40	
		21	54.97			22	58.30	
		17	55.31			15	56.91	
TS5-1	AR, 5min. Mixing	36	76.95	56	AD, 5min. Mixing	38	77.37	54
		28	56.44			29	52.64	
		22	56.32			20	52.86	
		15	55.47			16	55.59	
TS5-2	AR, 5min. Mixing	36	76.38	57	AD, 5min. Mixing	38	77.37	54
		28	55.69			29	52.64	
		22	56.47			20	52.86	
		17	57.32			16	55.59	
TS5-3	AR, 5min. Mixing	34	76.74	61	AD, 5min. Mixing	35	81.77	60
		27	60.05			28	60.56	
		21	62.76			21	59.11	
		15	63.31			16	59.23	
TS6-1	AR, 5min. Mixing	35	71.94	54	AD, 5min. Mixing	32	71.04	56
		27	53.48			27	56.39	
		22	54.36			22	55.51	
		16	54.03			16	53.78	

Liquid limits comparison between Multipoint and One-point test methods (continued)

Sample design.	Sample pretreatment	No. of Blows	One-point LL (%)	Multi point LL (%)	Sample pretreatment	No. of Blows	One-point LL (%)	Multipoint LL (%)
TS6-2	AR, 5min. Mixing	36	78.09	58	AD, 5min. Mixing	34	67.81	52
		28	56.97			26	51.26	
		23	57.73			20	50.84	
		17	58.51			15	50.78	
TS7-1	AR, 5min. Mixing	36	71.55	56	AD, 5min. Mixing	35	81.63	62
		27	56.53			28	62.83	
		20	57.47			21	62.14	
		15	56.86			16	61.63	
TS7-2	AR, 5min. Mixing	36	72.00	56	AD, 5min. Mixing	36	76.61	57
		28	54.63			28	56.45	
		22	57.09			22	57.18	
		16	55.76			16	57.95	
TS8-1	AR, 5min. Mixing	35	78.64	59	AD, 5min. Mixing	37	80.06	57
		28	57.68			28	56.42	
		22	58.93			20	56.99	
		16	59.00			16	55.87	
TS8-2	AR, 5min. Mixing	36	77.64	59	AD, 5min. Mixing	36	72.46	54
		29	57.36			28	53.16	
		23	59.21			21	54.53	
		17	60.81			17	55.64	
TS9-1	AR, 5min. Mixing	35	75.53	57	AD, 5min. Mixing	35	83.29	62
		28	57.20			29	60.91	
		23	58.52			21	60.81	
		17	57.35			16	61.61	
TS9-2	AR, 5min. Mixing	38	86.74	59	AD, 5min. Mixing	35	72.12	55
		29	58.64			28	54.24	
		21	58.41			22	55.83	
		14	56.58			16	54.78	
TS10-1	AR, 5min. Mixing	36	80.85	59	AD, 5min. Mixing	36	78.12	58
		28	58.18			28	56.94	
		21	57.84			21	57.60	
		14	57.96			16	57.37	
TS11-1	AR, 5min. Mixing	36	77.95	57	AD, 5min. Mixing	36	81.09	63
		28	56.02			28	63.57	
		22	56.52			21	63.04	
		15	56.10			16	62.10	
TS12-1	AR, 5min. Mixing	37	78.84	57	AD, 5min. Mixing	38	74.61	51
		29	56.84			29	51.49	
		23	56.81			19	50.06	
		17	57.29			14	49.80	
TS13-1	AR, 5min. Mixing	37	79.98	57	AD, 5min. Mixing	33	69.54	55
		29	57.54			27	54.55	
		23	57.30			21	55.98	
		17	60.60			15	55.66	
TS13-2	AR, 5min. Mixing	34	67.81	53	AD, 5min. Mixing	38	80.96	55
		26	52.27			27	55.32	
		21	53.04			21	54.22	
		16	53.07			16	54.29	

Liquid limits comparison between Multipoint and One-point test methods (continued)

Sample design.	Sample pretreatment	No. of Blows	One-point LL (%)	Multi point LL (%)	Sample pretreatment	No. of Blows	One-point LL (%)	Multipoint LL (%)
TS14-1	AR, 5min. Mixing	35	73.63	57	AD, 5min. Mixing	37	78.06	55
		28	55.53			28	54.84	
		23	57.99			22	54.99	
		18	58.55			16	53.84	
TS14-2	AR, 5min. Mixing	36	71.82	53	AD, 5min. Mixing	37	73.04	51
		28	53.05			27	51.01	
		22	52.20			20	50.03	
		15	50.50			14	49.28	
TS14-3	AR, 5min. Mixing	35	74.49	57	AD, 5min. Mixing	36	69.21	51
		27	56.27			29	50.72	
		21	56.70			22	50.01	
		14	56.20			16	50.02	
TS15-1	AR, 5min. Mixing	37	77.54	58	AD, 5min. Mixing	36	75.83	54
		29	56.17			28	54.09	
		22	59.01			21	53.50	
		14	57.74			16	53.52	
TS16-1	AR, 5min. Mixing	36	75.95	59	AD, 5min. Mixing	37	66.60	47
		28	57.57			28	47.29	
		22	61.66			22	47.01	
		17	59.48			15	46.99	
Sample-A (from A.A.)	AR, 5min. Mixing	36	70.53	51	AD, 5min. Mixing	38	72.39	50
		29	50.48			29	50.5	
		22	51.23			21	50.1	
		16	50.44			15	48.88	
Sample-B (from A.A.)	AR, 5min. Mixing	34	38.45	38	AD, 5min. Mixing	34	46.13	38
		28	39.70			27	36.04	
		21	38.09			21	38.82	
		14	37.64			14	41.48	

Activity number

Skempton's colloidal activity is determined as the ratio of the plasticity index and the quantity of colloidal clay particles present in soil. Skempton classifies clays according to their activity number. Following his classification, three degrees of colloidal activity have been established as indicated below in Table 4.10 as per Eq. 4.2. The activity of clay is expressed by an activity number “Ac” and defined as

$$\text{Activity number, Ac} = \frac{PI}{C} \text{ --Eq. 4.2}$$

Where C is the percent of clay fraction finer than 2 micron and PI is the plasticity index.

Skempton considers that the significant change in volume of a clay soil during shrinking or swelling is a function of plasticity index and the quantity of colloidal clay particles present in the soil; hence, activity number has been used as an index property to determine the swelling potential of clays (Das, 1985; Teferra & Leikun, 1999). Colloidal activity number values for the soils in research area were calculated and summarized hereto in Table 4.11.

Table 4.10 Degree of Colloidal Activity (Teferra & Leikun, 1999)

Activity	*Degree of activity*
< 0.75	Inactive clay
0.75 - 1.25	Normal clay
> 1.25	Active clay

Skempton (1953) has shown that, for kaolinite clay, the activity lies between 0.33 and 0.46 (Dibisa, 2008). The low value for this particular soil is due to the coating of Sesquioxides which reduces the specific surface area of the clay particles and hence suppresses the activity. The result for the soils under investigation is in agreement with the geochemical (XRF analysis) and mineralogical (XRD analysis) test results which are discussed in section 4.2.3 and clearly show that the soils are kaolinitic clays (i.e., inactive clays).

From Table 4.11, one can see that Skempton's colloidal activity number for the soils under investigation is less than 1.25; hence, it is true that the lateritic clay soils are classified as normal or inactive which is also in agreement with Morin W.J. and Todor P.C. (Lyon Associates, 1971).

Table 4.11 Skempton's colloidal activity number

Sample design.	**Sample Pre-treatment**	**Plasticity Index, PI (%)**		**Per cent of clay fraction finer than 2 micron (%)**	**Colloidal Activity, Ac (%)**	
		(5min. Mix.)	**(30min. Mix.)**		**(Using 5min. Mix. PI)**	**(Using 30min. Mix. PI)**
TS1-1	AR	20	22	45.45	0.44	0.48
	AD	22	24	58.62	0.37	0.41
	OD	17	18	56.84	0.30	0.31
TS1-2	AR	23	27	55.26	0.41	0.50
	AD	26	30	50.56	0.51	0.59
	OD	29	30	43.68	0.67	0.68
TS2-1	AR	19	25	61.57	0.31	0.41
	AD	26	34	44.28	0.58	0.76
	OD	22	26	49.74	0.44	0.53
TS2-2	AR	22	28	39.30	0.56	0.70
	AD	24	28	43.28	0.55	0.65
	OD	25	29	31.71	0.80	0.92
TS3-1	AR	19	28	50.17	0.38	0.55
	AD	22	27	45.98	0.48	0.58
	OD	16	23	47.68	0.34	0.47
TS3-2	AR	24	31	51.86	0.46	0.59
	AD	23	27	60.92	0.38	0.44
	OD	28	32	48.04	0.58	0.66
TS4-1	AR	18	24	52.55	0.35	0.45
	AD	20	25	50.17	0.40	0.50
	OD	20	23	40.73	0.48	0.56
TS4-2	AR	21	28	50.75	0.41	0.56
	AD	21	27	54.02	0.40	0.49
	OD	25	31	42.49	0.59	0.74
TS5-1	AR	21	26	46.79	0.45	0.56
	AD	22	28	53.57	0.41	0.53
	OD	19	24	46.92	0.40	0.52
TS5-2	AR	21	25	56.05	0.38	0.45
	AD	19	24	44.01	0.43	0.54
	OD	17	22	50.10	0.34	0.44
TS5-3	AR	24	27	58.13	0.41	0.47
	AD	24	31	47.68	0.50	0.66
	OD	20	24	66.47	0.30	0.37
TS6-1	AR	17	22	41.01	0.43	0.53
	AD	25	31	38.01	0.66	0.82
	OD	14	17	58.69	0.23	0.29
TS6-2	AR	26	32	31.75	0.83	1.00
	AD	20	25	59.69	0.34	0.43
	OD	22	27	67.80	0.32	0.39
TS7-1	AR	15	24	47.62	0.31	0.50
	AD	23	30	38.50	0.61	0.77
	OD	25	29	53.99	0.47	0.54
TS7-2	AR	22	27	49.31	0.45	0.55
	AD	16	21	51.27	0.31	0.41
	OD	28	33	83.49	0.34	0.39
TS8-1	AR	26	33	52.57	0.50	0.63
	AD	28	32	50.00	0.56	0.63
	OD	19	24	65.94	0.29	0.37

Skempton's colloidal activity number (continued)

Sample design.	**Sample Pre-treatment**	**Plasticity Index, PI (%)**		**Per cent of clay fraction finer than 2 micron (%)**	**Colloidal Activity, Ac (%)**	
		(5min. Mix.)	**(30min. Mix.)**		**(Using 5min. Mix. PI)**	**(Using 30min. Mix. PI)**
TS8-2	AR	24	29	44.54	0.53	0.64
	AD	23	27	42.12	0.54	0.65
	OD	18	23	59.06	0.31	0.39
TS9-1	AR	20	27	37.98	0.52	0.71
	AD	28	31	36.78	0.76	0.85
	OD	30	35	80.39	0.37	0.44
TS9-2	AR	21	26	34.75	0.62	0.75
	AD	22	27	38.78	0.58	0.69
	OD	23	27	62.82	0.37	0.43
TS10-1	AR	23	28	46.69	0.50	0.59
	AD	26	31	48.33	0.54	0.63
	OD	17	22	43.69	0.38	0.50
TS11-1	AR	16	21	50.54	0.31	0.41
	AD	25	30	29.89	0.82	0.99
	OD	26	31	38.68	0.67	0.80
TS12-1	AR	22	28	52.84	0.42	0.53
	AD	13	19	47.60	0.27	0.39
	OD	15	20	53.13	0.29	0.37
TS13-1	AR	17	23	53.52	0.32	0.43
	AD	21	23	33.15	0.64	0.70
	OD	16	21	21.21	0.76	0.99
TS13-2	AR	18	23	41.25	0.44	0.56
	AD	20	21	40.78	0.49	0.51
	OD	21	25	26.29	0.81	0.97
TS14-1	AR	20	26	40.33	0.50	0.63
	AD	22	27	55.14	0.40	0.50
	OD	15	20	47.20	0.32	0.43
TS14-2	AR	15	17	18.60	0.81	0.94
	AD	15	23	40.93	0.38	0.55
	OD	18	24	51.03	0.36	0.47
TS14-3	AR	24	29	59.97	0.39	0.48
	AD	19	26	42.49	0.45	0.60
	OD	14	19	35.98	0.40	0.53
TS15-1	AR	19	25	52.48	0.36	0.48
	AD	22	27	44.96	0.49	0.59
	OD	20	23	49.03	0.41	0.48
TS16-1	AR	24	29	51.52	0.46	0.56
	AD	14	16	52.36	0.27	0.31
	OD	20	22	52.89	0.38	0.42

4.2.1.4 Shrinkage limit

4.2.1.4.1 General

The shrinkage limit is the dividing line between the semisolid and solid states. It is quantified for a given soil as specific water content, and from a physical standpoint it is the water content that is just sufficient to fill the voids when the soil is at the minimum volume it will attain on drying. Below the shrinkage limit, any water content change will not result in volume change; above the shrinkage limit, any water change will result in accompanying volume change.

Shrinkage limit, SL can be calculated as follows:

$$\mathrm{SL} \quad = \quad \omega - \left((\frac{\mathrm{V - V_o}}{W_o})\gamma_\omega \times 100 \right) \text{-- Eq. 4.3}$$

Where: SL= shrinkage limit (expressed as a percentage)

ω = water content of wet soil in the shrinkage dish, %

V = volume of wet soil pat (same as volume of shrinkage dish), cm^3

$\mathrm{V_o}$ = volume of oven-dried soil pat, cm^3

$\mathrm{W_o}$ = weight of oven-dried soil pat, g

γ_ω = unit weight of water, 1 $\mathrm{g/cm}^3$

Another soil parameter that often determined in conjunction with the shrinkage limit is the shrinkage ratio, which is an indicator of how much volume change may occur as changes in water content above the shrinkage limit takes place. The shrinkage ratio is defined as the ratio of a given volume change, expressed as a percentage of the dry volume, to the corresponding change in water content above the shrinkage limit, expressed as a percentage of the mass of oven-dried soil. In equation form,

$$\mathrm{R} = \left(\frac{\Delta \mathrm{V/V_o}}{\Delta\omega / W_o} \right) = \frac{W_o}{V_o} \text{--Eq. 4.4}$$

Where: R = Shrinkage ratio

$\Delta\, \omega = (\Delta V)(\gamma_w)$ = change in water content (gm), where unit weight of water is g/cm^3

ΔV = soil volume change (cm^3)

V_o = volume of oven-dried soil (cm^3)

W_o = weight of oven-dried soil pat (gm)

The shrinkage limit and shrinkage ratio are particularly useful in analyzing soils that undergo large volume changes with changes in water content (such as Montimorillonite and Illite clays). The shrinkage ratio gives an indication of how much volume change may occur as changes in water content above the shrinkage limit takes place.

For this research work a linear shrinkage values were determined according to British Standard, BS, 1377 in order to determine the shrinkage characteristics of the soils. This method is an alternative to the volumetric shrinkage limit which is discussed above. Linear shrinkage (LS) can be calculated as follows:

$$LS = \frac{L_o - L_f}{L_o} \text{---Eq. 4.5}$$

Where: LS = linear shrinkage

L_o = length of wet soil bar

L_f = length of dry soil bar

4.2.1.4.2 Test procedures

The general procedure for determining shrinkage limit is begun by placing the sample in an evaporating dish and mixing it with enough distilled water to fill the soil voids completely. After the shrinkage dish is coated with petroleum jelly, wet soil is taken from the evaporating dish with spatula and placed in the shrinkage dish. This should be done in three parts, with steps taken each time to drive all air out of the soil. After the shrinkage dish and wet soil are weighed, the soil is set aside to dry in air. It is then oven-dried overnight, after which the shrinkage dish and dry soil are weighed again. After the oven-dried soil pat is removed from the shrinkage dish, its volume can be determined by mercury displacement. The weight and volume of empty shrinkage dish must also be determined. The latter (i.e. the volume of the shrinkage dish) is also done by mercury displacement, and it is the same as the volume of wet soil pat. With these data known, the shrinkage limit can be determined by Eq. 4.3. The actual step-by-step procedure can be seen in ASTM D 427-83 and AASHTO T-92.

For the case of computation of the linear shrinkage, a pulverized sample passed through a No. 40 sieve was mixed in a dish with enough distilled water to fill the soil voids completely and rolled in to threads and put in the Shrinkage Mould. After the length of wet soil, which was rolled into threads, is measured, the soil is set aside to dry in air. It is then oven-dried overnight, after which the final length of the soil thread is measured again. Then the linear shrinkage is computed using Eq. 4.5. Hence, the shrinkage limits were checked using the computed linear shrinkage values.

4.2.1.4.3 Test results and discussions

The laboratory linear shrinkage tests were carried out on air-dried (or 50^{o}C oven temp.) and oven-dried (105^{o}C oven temp.) prepared samples and the results are summarized in Table 4.12.

From the test results one can see that air-dried soil samples have higher values of linear shrinkage than that of oven-dried soil samples even if the variation is insignificant. Hence, for soil samples under investigation higher drying temperatures during sample preparation causes the soil particles to come closer and create higher cementation by sesquioxides that can’t be reversed upon rewetting as a result linear shrinkage values will be reduced.

Table 4.12 Linear Shrinkage values for different pretreatment conditions

Sample Designation	***Liquid Limits (LL) %***		***Plastic Limits (PL) %***		***Plastic Index (PI) %***		***Linear Shrinkage (SL) %***	
	AD	***OD***	***AD***	***OD***	***AD***	***OD***	***AD***	***OD***
TS1-1	55.9	47.2	34.4	29.9	21.6	17.3	8.5	7.2
TS1-2	56.3	52.6	30.6	23.4	25.6	29.2	8.5	7.8
TS2-1	61.0	54.0	35.4	31.9	25.6	22.1	8.8	8.4
TS2-2	58.2	58.0	34.4	32.6	23.8	25.4	8.9	8.0
TS3-1	56.6	48.9	34.3	32.6	22.2	16.3	8.3	7.0
TS3-2	58.5	60.0	35.2	32.4	23.4	27.7	9.2	8.4
TS4-1	57.3	53.3	37.5	33.6	19.9	19.7	9.0	8.0
TS4-2	58.4	57.2	37.0	32.2	21.4	25.0	8.9	8.0
TS5-1	54.1	53.2	32.1	34.5	22.0	18.7	8.8	8.4
TS5-2	54.1	50.9	35.2	33.9	18.9	17.0	9.2	8.6
TS5-3	60.3	52.0	36.4	32.4	23.8	19.6	8.5	8.0
TS6-1	56.1	48.1	30.8	34.5	25.3	13.6	8.7	8.4
TS6-2	51.5	54.0	31.3	32.2	20.3	21.8	8.5	8.2
TS7-1	62.2	56.8	38.9	31.3	23.3	25.5	8.0	7.4
TS7-2	57.2	62.4	41.6	34.2	15.7	28.2	7.9	7.3
TS8-1	56.9	52.7	29.1	33.5	27.8	19.2	11.6	10.5
TS8-2	54.4	50.1	31.6	31.8	22.8	18.4	11.2	10.1
TS9-1	61.7	62.0	33.7	32.3	28.0	29.7	9.5	8.4
TS9-2	55.0	54.2	32.6	31.1	22.4	23.1	9.0	8.0
TS10-1	57.5	49.9	31.4	33.3	26.1	16.7	8.8	8.1
TS11-1	63.4	56.4	38.8	30.3	24.6	26.1	8.6	8.0
TS12-1	51.2	48.6	38.4	33.3	12.9	15.2	8.3	7.8
TS13-1	55.4	49.0	34.1	32.8	21.3	16.2	8.0	7.5
TS13-2	55.3	54.4	35.4	33.0	19.8	21.4	8.8	8.6
TS14-1	55.1	48.6	33.1	33.6	22.0	15.0	7.9	7.5
TS14-2	51.0	51.1	35.6	32.7	15.4	18.5	7.8	7.3
TS14-3	50.5	45.6	31.4	31.2	19.1	14.4	7.8	7.4
TS15-1	54.3	53.0	32.3	32.7	22.1	20.3	8.6	8.3
TS16-1	47.5	54.1	33.5	34.0	14.0	20.1	8.7	8.4

4.2.1.5 Free swell

4.2.1.5.1 General

Both the amount of swelling and the magnitude of swelling pressure are known to be dependent on the clay minerals, the soil mineralogy and structure, fabric and several physio-chemical aspects of the soil (Sintayehu, 2003), Among clay minerals Montimorillonite influence the magnitude of swelling as compared to Illites and Kaolinites.

The soil mineralogy of laterites on the other hand is affected by different factors: climate, topography, geographical location, nature of the base rock from which the soil is derived. For the soils under study, Western Ethiopia laterites, all the physical and chemical test results revealed that the soils constitute less active clay minerals like Kaolinite and halloysite (Zelalem, 2005; Wakuma, 2007; Dibisa, 2008). Generally, among the clay minerals which are contributing to swelling of soils Montimorillonites (Smectite group) and Illites are the most common once. Drying of soil samples also makes soil particles to come closer and hide the potential of some of the active minerals to swell (Dibisa, 2008).

Free swell is given by:

$$\text{Free Swell (\%)} = \frac{Vf - Vi}{Vi} \times 100 \quad \text{--Eq. 4.6}$$

Where V_f = final volume

V_i = initial volume

4.2.1.5.2 Test procedures

The free swell test can be done by pouring very slowly 10cm^3 of dry soil which has passed No. 40 (0.425mm) sieve into a 100cm^3 graduated cylinder filled with distilled water. And the cylinder is left to stay for approximately 24 hours until all the soils settle completely to the bottom of the cylinder. Hence, the final volume of the suspension being read and the free dwell is computed using Eq. 4.6.

4.2.1.5.3 Test results and discussions

The laboratory free swell tests were done on air-dried (or 50^{o}C oven temp.) and oven-dried (105^{o}C oven temp.) samples and the results are summarized in Table 4.13. As can be seen from the test results the free swell of the soils under investigation range from 20% to 45%. Generally, soils with free swell of less than 50% are considered to have low degree of expansion, Teferra and Leikun (1999). Accordingly, the soils in Nedjo, Jarso and Begi areas are non-expansive soil (or low in expansion).

Table 4.13 Free Swell test results at different pre-treatment conditions

Sample designation	***Free Swell, Air-Dried sample (%)***	***Free Swell, Oven-Dried sample (%)***
TS1-1	42.5	35
TS1-2	35	32.5
TS2-1	35	30
TS2-2	35	32.5
TS3-1	45	40
TS3-2	39	35
TS4-1	35	33
TS4-2	30	23
TS5-1	35	32.5
TS5-2	31	25
TS5-3	29	25
TS6-1	39	35
TS6-2	35	29
TS7-1	40	40
TS7-2	36	31
TS8-1	29	29
TS8-2	25	23
TS9-1	45	35
TS9-2	45	42.5
TS10-1	45	41
TS11-1	36	30
TS12-1	36	32
TS13-1	40	30
TS13-2	45	39
TS14-1	30	25
TS14-2	35	30
TS14-3	38	33
TS15-1	32	25
TS16-1	30	25
Sample-A (from A.A.)	23	21
Sample-B (from A.A.)	26	22

4.2.1.6 Specific Gravity

4.2.1.6.1 General

The specific gravity, Gs, is used to calculate parameters such as clay fraction, void ratio and porosity. In residual soils the specific gravity may be unusually high or unusually low. It is thus essential that the specific gravity be determined in the laboratory using an accepted standard test procedure, for the purpose of carrying out these calculations. The soil has to be in its natural moisture content. Pre-test drying of the sample should be avoided as it tends to reduce the measured specific gravity as compared with the soils at their natural moisture content (Blight, 1997; Wakuma, 2007). The dry mass of the soil used in the test should be calculated by drying the soil specimen after the specific gravity test has been completed. Due to the outcome of section 4.2.1.1 that even though the amount was not very high the soils sample under investigation, Nedjo, Jarso, Begi areas, do have structural water or water of hydration that leads to irreversible changes up on drying as compared with the soil samples taken from Addis Ababa, it is therefore necessary to air-dry the soil, or to dry at reduced temperature for the computation of the dry mass after the test rather than drying to higher (105^{o}C) oven temperature.

4.2.1.6.2 Test procedures

The soil samples under investigation were tested using the ASTM testing procedures, designation ASTM D 854-92. The tests were conducted at different pretreatment conditions (as-received, air-dried and oven-dried) in order to see the effect of pre-test drying, on the test results. During the test the dry masses of air-dried and oven-dried soils samples were measured initially before carrying out the test; however, the dry mass of the as-received soils were measured after the specific gravity test has been completed by oven drying the soil specimens with 50^{o}C oven temperature.

4.2.1.6.3 Test results and discussions

From the test results, which are summarized in Table 4.14 and Figure 4.15, one can see that air-dried and oven-dried pretreatment conditions give nearly similar values; however, the specific gravity is slightly reduced with oven drying temperature. In addition to this it can be seen that the as received pretreatment condition gives higher values of specific gravity than the other two pretreatment conditions. This is due to the dehydration and/or aggregation of clay particles of the lateritic soils up on drying (Lyon Associates, 1971; Blight, 1997; Zelalem, 2005; Wakuma, 2007; Dibisa, 2008).

The specific gravity of soils found in Western Ethiopia areas is tend to reduce with increasing the temperature from in-situ condition to oven drying temperature. As discussed before, the decrease in specific gravity is due to the tendency of lateritic soils to dehydrate and/or aggregate the clay particles upon drying.

As can be seen from the test results, one can see that the range of values is from 2.33 to 3.15. This is in agreement with Morin W.J. and Todor P.C. in Lyon Associates (1971) that the specific gravities of lateritic soils can be low or be very high even up to 3.5; such a high value is due to high iron content of the soils. This was confirmed by chemical analysis in section 4.2.3.

Table 4.14 Specific Gravity values at different pretreatment /testing/ conditions

Sample Name	***Sample Location***		***Air-dried***	***Oven-dried***	***As-received***
	Station, Offset	***Depth***			
TS1-1	10+880, 1.5km RHS	0.6m	2.63	2.71	3.10
TS1-2	10+880, 1.5km RHS	2.0m	2.68	2.63	2.94
TS2-1	16+280, 20m RHS	1.5m	2.97	2.71	3.15
TS2-2	16+280, 20m LHS	3.0m	2.98	2.84	3.20
TS3-1	20+000, 50m RHS	0.6m	2.76	2.74	2.85
TS3-2	20+000, 50m RHS	2.0m	2.84	2.74	3.24
TS4-1	30+000, 20m RHS	2.0m	2.75	2.68	2.94
TS4-2	30+000, 20m RHS	3.0m	2.70	2.44	2.83
TS5-1	35+980, 120m RHS	0.6m	2.79	2.51	2.98
TS5-2	35+980, 120m RHS	1.8m	2.72	2.72	3.06
TS5-3	35+980, 120m RHS	2.5m	2.81	2.40	2.68
TS6-1	44+080, 40m LHS	1.0m	2.78	2.61	2.91
TS6-2	44+080, 40m LHS	2.0m	2.73	2.73	2.99
TS7-1	49+100, 20m LHS	1.5m	2.87	2.73	3.12
TS7-2	49+100, 20m RHS	3.5m	2.72	2.68	3.13
TS8-1	53+000, 40m RHS	1.5m	2.46	2.63	2.95
TS8-2	53+000, 40m RHS	3.0m	2.69	2.54	3.00
TS9-1	58+000, 50m LHS	0.6m	2.50	2.63	2.65
TS9-2	58+100, 50m LHS	1.5m	2.88	2.60	2.90
TS10-1	58+200, 200m LHS	0.6-1.5m	2.75	2.66	2.89
TS11-1	58+200, 250m LHS	1.0-2.0m	2.88	2.86	2.97
TS12-1	70+040, 300m RHS	1.0-2.0m	2.72	2.70	2.80
TS13-1	70+840, 20m LHS	1.0m	2.78	2.77	2.88
TS13-2	70+840, 20m LHS	3.0m	2.82	2.33	2.70
TS14-1	74+300, 30m RHS	1.0m	2.62	2.47	2.76
TS14-2	74+300, 30m RHS	1.5m	2.81	2.78	2.94
TS14-3	74+300, 30m RHS	3.0m	2.60	2.47	2.88
TS15-1	84+200, 200m RHS	1.0-2.0m	2.59	2.38	2.68
TS16-1	84+200, 200m RHS	1.0m	2.70	2.64	2.88
Sample-A	*from Entoto (A.A.)*	1.5m	2.61	2.60	2.63
Sample-B	*from Entoto (A.A.)*	1.0m	2.60	2.58	2.61

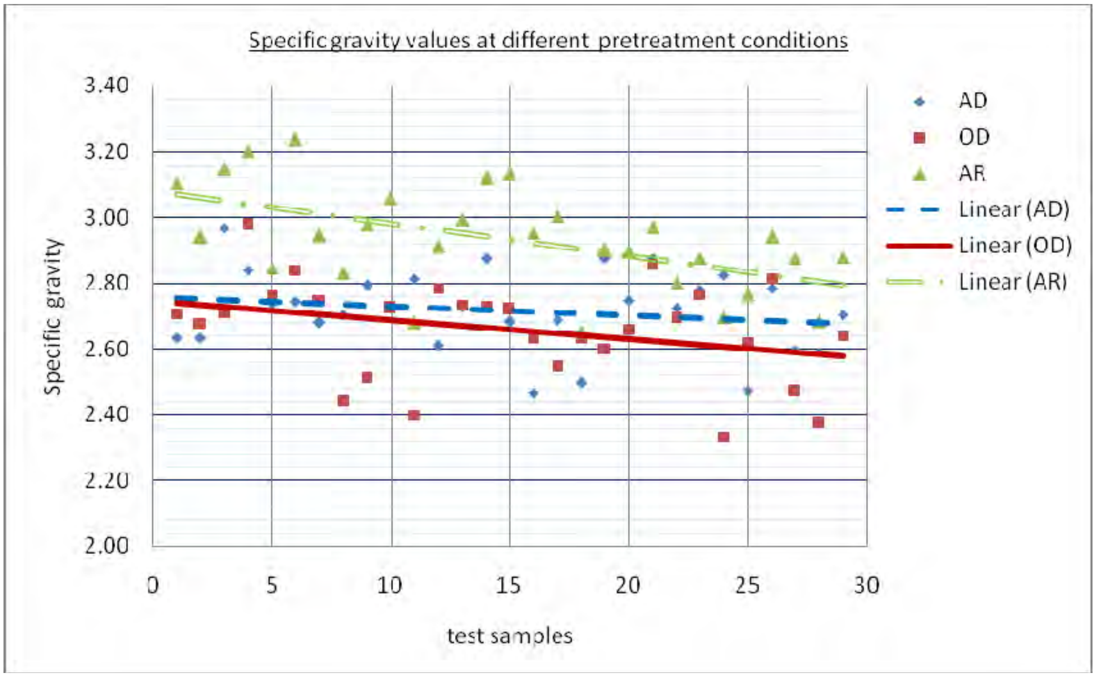


Figure 4.15 Effect of different pretreatments on specific gravity values

4.2.2 Classification of the Soils

4.2.2.1 General

Though different disciplines find a soil classification based purely on particle-size classification satisfactory for their professional needs, the Civil Engineer requires a classification that has engineering applications. The demand led to the development of a number of engineering soil classifications. All widely used engineering soil classifications involve a combination of particle size analysis and measures of plasticity (Dibisa, 2008).

There are two main soil classification systems in common use for engineering purposes. The Unified Soil Classification System [ASTM D 2487-93] is used for virtually all geotechnical engineering work except highway and road construction, where the AASHTO classification system [AASHTO M 145-87] is used. *Both systems use the results of grain-size analysis and determinations of Atterberg limits to determine a soil's classification.* Soil components may be described as gravel, sand, silt, or clay. A soil comprising one or more of these components is given a descriptive name and a designation consisting of letters or letters and numbers which depend on the relative proportions of the components and the plasticity characteristics of the soil.

Engineering soils are subdivided into two main groups as a function of their predominant sizes and associated plasticity. The coarse-grained soils are composed of sand size and larger particles. They are separated into size ranges by sieving of materials up to cobble size. Except for minor fractions of plastic fines, they characteristically are non-plastic. The fine grained soils consist predominantly of silt and clay-sized particles with differing degrees of plasticity measured by their Atterberg limits rather than by sieving and settling velocity methods.

In this thesis work, classification was made based on the two most popular engineering soil classifications namely: Unified Soil Classification System (USCS), and AASHTO classification system. In addition to these classification systems, classification /soil grouping/ was made based on the mineralogical composition of a soil as proposed by Wesley L.D. and Irfan (Blight, 1997); and soil grouping based on genetic basis and soil forming factors was also made as proposed by D'hoore (1964) (Lyon Associates, 1971).

4.2.2.2 Unified Soil Classification System (USCS)

The Unified Soil Classification System is based on the airfield classification system developed by A. Casagrande during World War II. With some modification it was jointly adopted by several U.S. government agencies in 1952. Additional refinements were made and it is currently standardized as ASTM D 2487-93. It is used in the U.S. and much of the world for geotechnical work other than roads and highways (Chen & Liew, 2003).

In the unified system soils are designated by a two-letter symbol: the first identifies the primary component of the soil, and the second describes its grain size or plasticity characteristics. For example, poorly graded sand is designated SP and low plasticity clay is CL. Five first-letter symbols are used: G for gravel, S for sand, M for silt, C for clay, and O for organic soil.

Clean sands and gravels (having less than 5% passing the No. 200 sieve) are given a second letter P if poorly graded or W if well graded. Sands and gravels with more than 12% by weight passing the No. 200 sieve are given a second letter M if the fines are silty or C if fines are clayey. Sands and gravels having between 5 and 12% are given dual classifications such as SP-SM. Silts, clays, and organic soils are given the second letter H or L to designate high or low plasticity. The specific rules for classification are summarized as follows and described in detail in ASTM D 2487.

Organic soils are distinguished by a dark-brown to black color, an organic odor, and visible fibrous matter.

For soils that are not notably organic the first step in classification is to consider the percentage passing the No. 200 sieve. If less than 50% of the soil passes the No. 200 sieve, the soil is coarse grained, and the first letter will be G or S; if more than 50% passes the No. 200 sieve, the soil is fine grained and the first letter will be M or C.

For coarse-grained soils, the proportions of sand and gravel in the coarse fraction (not the total sample) determine the first letter of the classification symbol. The coarse fraction is that portion of the total sample retained on a No. 200 sieve. If more than half of the coarse fraction is gravel (retained on the No. 4 sieve), the soil is gravel and the first letter symbol is G. If more than half of the coarse fraction is sand, the soil is sand and the first letter symbol is S.

For sands and gravels the second letter of the classification is based on gradation for clean sands and gravels and plasticity of the fines for sands and gravels with fines. For clean sands (less than 5% passing the No. 200 sieve), the classification is well-graded sand (SW) if $Cu \geq 6$ and $1 \leq Cc \leq 3$. Both of these criteria must be met for the soil to be SW, otherwise the classification is poorly graded sand (SP). Clean gravels (less than 5% passing the No. 200 sieve) are classified as well-graded gravel (GW) if $Cu \geq 4$ and $1 \leq Cc \leq 3$. If both criteria are not met, the soil is poorly graded gravel (GP).

For sands and gravels where more than 12% of the total sample passes the No. 200 sieve, the soil is a clayey sand (SC), clayey gravel (GC), silty sand (SM), or silty gravel (GM). The second letter is assigned based on whether the fines classify as clay (C) or silt (M) as described for fine-grained soils below.

For sands and gravels having between 5 and 12% of the total sample passing the No. 200 sieve, both the gradation and plasticity characteristics must be evaluated and the soil is given a dual classification such as SP-SM, SP-SC, GW-GC, etc. The first symbol is always based on gradation, whereas the second is always based on plasticity.

For fine-grained soils and organic soils, classification in the unified system is based on Atterberg limits determined by the fraction passing the No. 40 sieve. The liquid limit and plasticity index are determined and plotted on the plasticity chart shown in Figure 4.16 or 4.17. The vertical line at LL = 50 separates high-plasticity soils from low-plasticity soils. The A-line separates clay from silt. The equation of the A-line is $PI = 0.73(LL - 20)$. The U-line is not used in classification but is an upper boundary of expected results for natural soils. Values plotting above the U-line should be checked for errors.

Inorganic soils with liquid limits below 50 that plot above the A-line and have PI values greater than 7 are lean clays and are designated CL; those with liquid limits above 50 that plot above the A-line are fat clays and are designated CH. Inorganic soils with liquid limits below 50 that plot below the A-line are silt and are designated ML; those with liquid limits above 50 that plot below the A-line are elastic silts and are designated MH. The plasticity chart has a shaded area; soils that plot in this area (above the A-line with PI values between 4 and 7) are silty clay and are given the dual symbol CL-ML. If the soil under consideration is the fines component of a dually classified sand or gravel, the soil is classified as SM-SC or GM-GC. Soils with sufficient organic contents to influence properties that have liquid limits below 50 are classified as OL; those with liquid limits above 50 are classified as OH. Soils that are predominantly organic, with visible vegetable tissue, are termed peat and given the designation Pt.

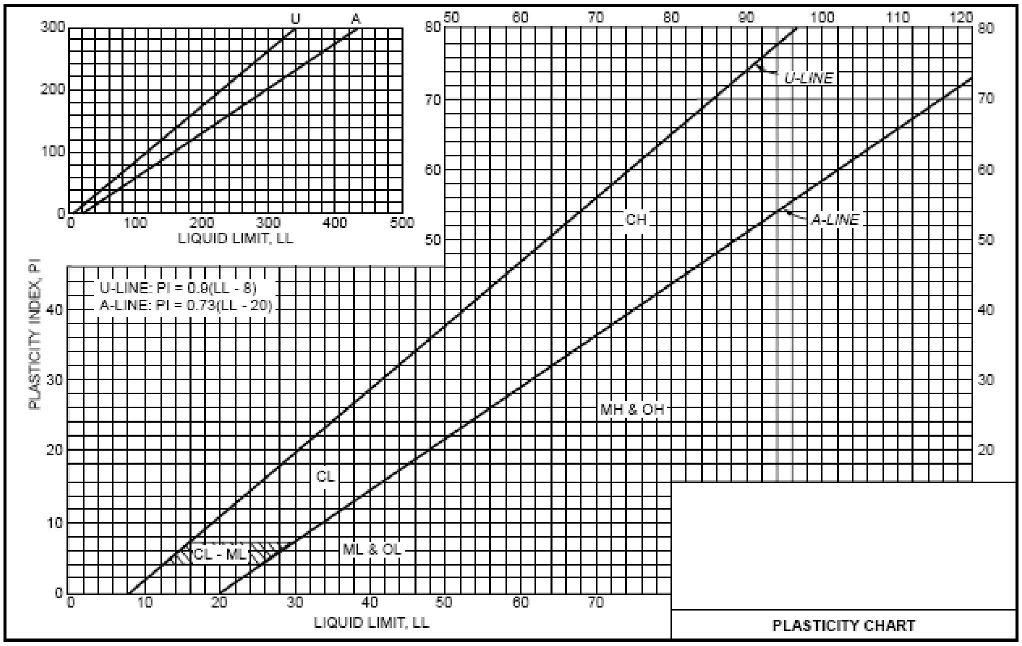


Figure 4.16 Plasticity chart for Unified Soil Classification System (Chen & Liew, 2003)

Plasticity Chart (for Unified Soil Classification System)

A high numerical value of plasticity index is an indication of the presence of high percentage of clay in the soil sample which implies that the plasticity values increase with the corresponding increase in clay contents.

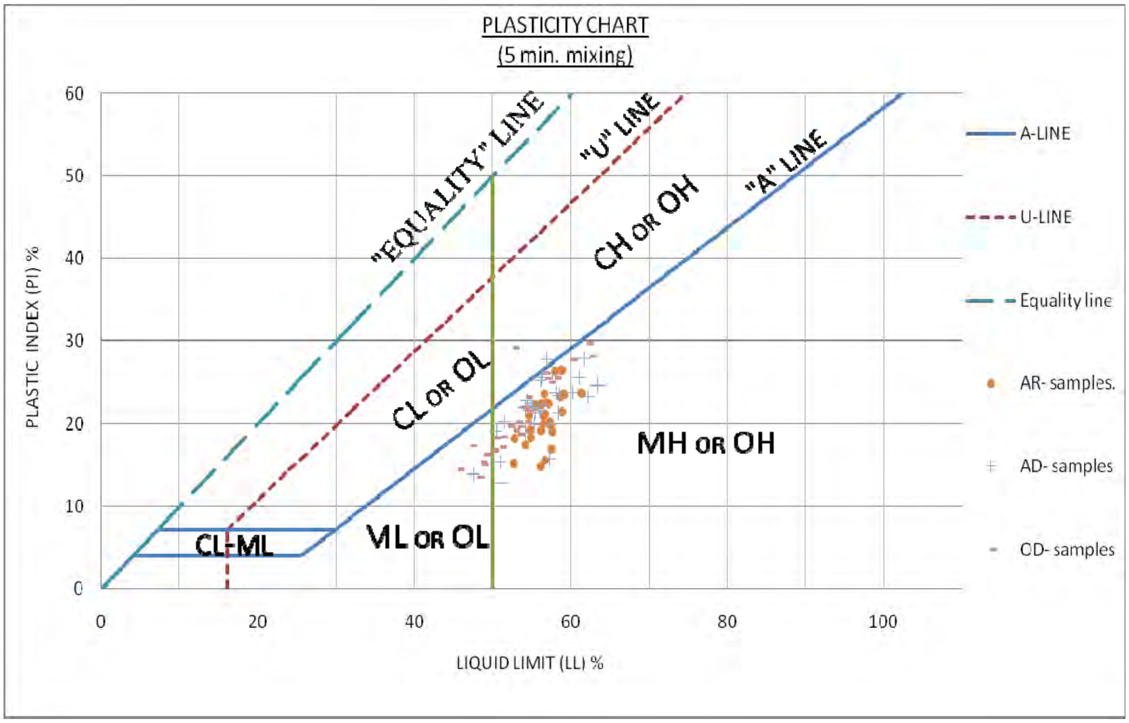
Plasticity index (PI) in relation to the liquid limit can provide information regarding the type of clay in the soil sample. This was done by means of a plasticity chart developed from soils tested from different parts of the world (Budhu, 2000). Clays, silts and organic soils lie in distinct region on the chart. As discussed previously, the A-line is defined by Eq. 4.1, which separates clays from silts. From the chart, Figure 4.17, it can be seen that all soil samples under investigation are lie below A-line which mean they fall in the region of silts. As soils containing minerals of chlorite, halloysite and kaolinite tend to fall in this region (Fredlund & Rahardjo, 1993; Zelalem, 2005) and lateritic soils consist of predominantly of kaolinite minerals, the soil samples under investigation are in agreement with the nature of lateritic soils.

As discussed above the U-line, which is defined by Eq. 4.2, is the upper limit of the correlation between plasticity index and liquid limit. Test results above this line indicates erroneously executed tests; hence, it is recommended that the tests should be checked for errors. As can be seen in the plasticity chart, Figure 4.17, all test results are fallen below the U-line; hence, the test results are considered acceptable.

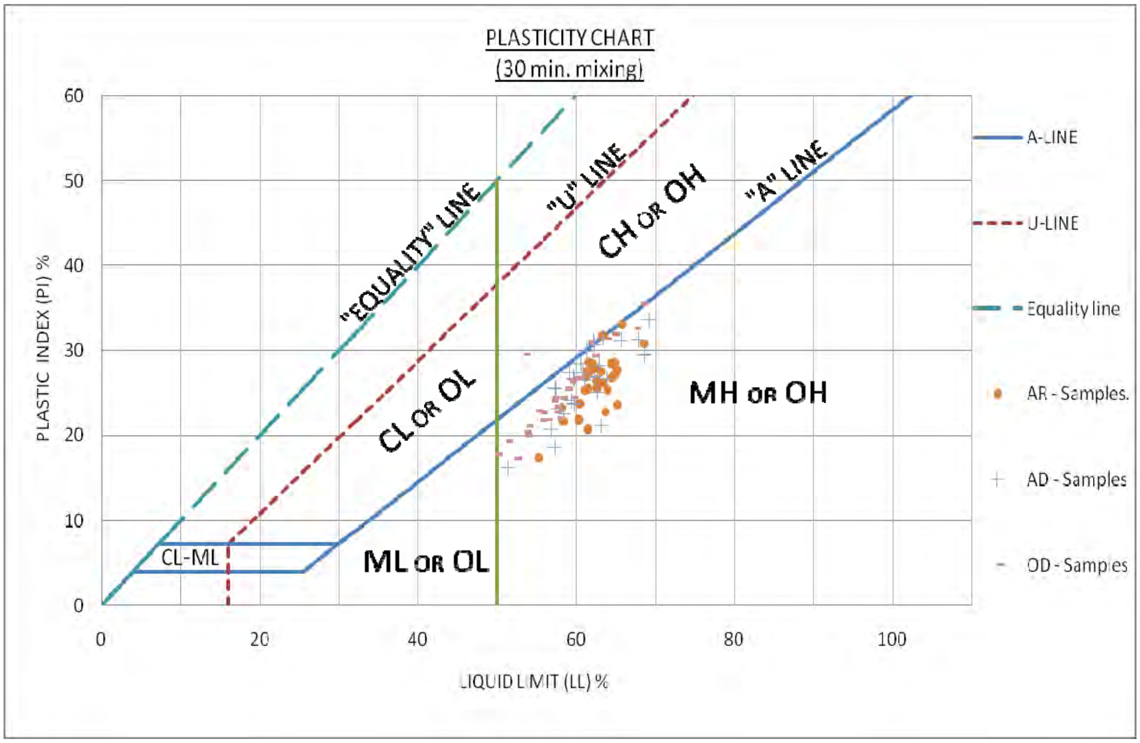
$PI = 0.73\,(LL-20)$……………………………………………………….…...Eq. 4.7

$PI = 0.90\,(LL-8)$……………………………………………………...........Eq. 4.8

Where: Both PI and LL values are expressed on percent.



a) 5 minutes of mixing time



b) 30 minutes of mixing time

Figure 4.17 Plasticity Charts for USC System

Table 4.15 Classification of soil samples according to USCS

Sample design.	**Sample Pre-treatment**	**Liquid Limit, LL (%)**	**Plasticity Index, PI (%)**	**%age amount of Particle Sizes**				**Classification According to USCS**	
				Gravel	**Sand**	**Silt**	**Clay**	**Group Symbol**	**Group Name**
TS1-1	AR	56	20	38.27	28.09	18.35	15.29	(GM)s	Silty Gravel with sand
	AD	56	22	31.02	27.52	17.16	24.31	(GM)s	Silty Gravel with sand
	OD	47	17	37.74	42.45	8.55	11.26	(SM)g	Silty Sand with gravel
TS1-2	AR	57	23	64.82	19.86	6.85	8.46	(GM)s	Silty Gravel with sand
	AD	56	26	57.98	21.6	10.1	10.33	(GM)s	Silty Gravel with sand
	OD	53	29	57.95	21.86	11.37	8.82	(GC)s	Clayey Gravel with sand
TS2-1	AR	55	19	54.67	31.33	5.38	8.62	(GM)s	Silty Gravel with sand
	AD	61	26	43.23	36.5	11.3	8.98	(GM)s	Silty Gravel with sand
	OD	54	22	47.04	35.73	8.66	8.57	(GM)s	Silty Gravel with sand
TS2-2	AR	56	22	42.37	43.34	8.68	5.62	(SM)g	Silty Sand with gravel
	AD	58	24	33.8	46.04	11.44	8.73	(SM)g	Silty Sand with gravel
	OD	58	25	35.5	50.15	9.8	4.55	(SM)g	Silty Sand with gravel
TS3-1	AR	56	19	53.72	18.01	10.16	10.23	(GM)s	Silty Gravel with sand
	AD	57	22	35.41	29.88	11.21	9.54	(GM)s	Silty Gravel with sand
	OD	49	16	34.18	30.72	14.19	12.93	(GM)s	Silty Gravel with sand
TS3-2	AR	61	24	33.76	39.63	12.81	13.8	(SM)g	Silty Sand with gravel
	AD	59	23	27.05	38.14	13.6	21.2	(SM)g	Silty Sand with gravel
	OD	60	28	27.59	48.72	12.31	11.38	(SM)g	Silty Sand with gravel
TS4-1	AR	55	18	22.75	34.69	20.19	22.36	(SM)g	Silty Sand with gravel
	AD	57	20	20.8	48.94	15.08	15.18	(SM)g	Silty Sand with gravel
	OD	53	20	22.28	39.74	22.51	15.47	(SM)g	Silty Sand with gravel
TS4-2	AR	55	21	67.47	6.25	4.6	4.74	GP-GM	Poorly-graded gravel with silt
	AD	58	21	62.13	12.1	8.81	10.35	GM	Silty Gravel
	OD	57	25	64.52	14.47	8.62	6.37	GM	Silty Gravel
TS5-1	AR	56	21	36.8	28.47	18.48	16.25	(GM)s	Silty Gravel with sand
	AD	54	22	30.62	33.43	16.69	19.26	(SM)g	Silty Sand with gravel
	OD	53	19	36.23	31.44	17.16	15.17	(GM)s	Silty Gravel with sand
TS5-2	AR	57	21	61.63	17.54	9.15	11.67	(GM)s	Silty Gravel with sand
	AD	54	19	64.82	18.33	9.44	7.42	(GM)s	Silty Gravel with sand
	OD	51	17	75.15	15.17	4.83	4.85	GP-GM	Poorly-graded gravel with silt
TS5-3	AR	61	24	62.53	18.92	6.46	8.97	(GM)s	Silty Gravel with sand
	AD	60	24	48.14	28.15	12.41	11.31	(GM)s	Silty Gravel with sand
	OD	52	20	58.11	28.2	4.59	9.1	(GM)s	Silty Gravel with sand
TS6-1	AR	54	17	74.81	14.91	6.07	4.22	GP-GM	Poorly-graded gravel with silt
	AD	56	25	64.21	16.69	15.06	4.04	(GM)s	Silty Gravel with sand
	OD	48	14	65.66	24.1	4.23	6.01	GP-GM	Poorly-graded gravel with silt
TS6-2	AR	58	26	49.83	32.22	12.25	5.7	(GM)s	Silty Gravel with sand
	AD	52	20	55.76	22.89	8.61	12.75	(GM)s	Silty Gravel with sand
	OD	54	22	70.38	15.55	4.53	9.54	(GM)s	Silty Gravel with sand
TS7-1	AR	56	15	59.92	13.91	12.55	11.41	GM	Silty Gravel
	AD	62	23	50.09	21.52	16.66	10.43	(GM)s	Silty Gravel with sand
	OD	57	25	55.33	20.35	11.19	13.13	(GM)s	Silty Gravel with sand

Classification of soil samples according to USCS (continued)

Sample design.	**Sample Pre-treatment**	**Liquid Limit, LL (%)**	**Plasticity Index, PI (%)**	**%age amount of Particle Sizes**				**Classification According to USCS**	
				Gravel	**Sand**	**Silt**	**Clay**	**Group Symbol**	**Group Name**
TS7-2	AR	56	22	62.8	14.46	10.26	9.98	GM	Silty Gravel
	AD	57	16	59.36	17.87	10.57	11.12	(GM)s	Silty Gravel with sand
	OD	62	28	58.9	29.66	1.89	9.56	GP-GM	Poorly-graded gravel with silt
TS8-1	AR	59	26	60.29	22.96	7.94	8.8	(GM)s	Silty Gravel with sand
	AD	57	28	55.73	26.16	9.05	9.05	(GC)s	Clayey Gravel with sand
	OD	53	19	60.9	24.45	4.99	9.66	(GM)s	Silty Gravel with sand
TS8-2	AR	59	24	67.62	16.08	9.04	7.26	(GM)s	Silty Gravel with sand
	AD	54	23	60.73	20.23	11.02	8.02	(GM)s	Silty Gravel with sand
	OD	50	18	57.89	30.19	4.88	7.04	GP-GM	Poorly-graded gravel with silt
TS9-1	AR	57	20	23.26	37.93	24.07	14.74	(SM)g	Silty Sand with gravel
	AD	62	28	13.93	48.62	23.67	13.77	SM	Silty Sand
	OD	62	30	16.67	30.96	10.27	42.09	s(MH)	Sandy Elastic Silt
TS9-2	AR	59	21	74.47	18	4.92	2.62	GP-GM	Poorly-graded gravel with silt
	AD	55	22	61.65	23.92	8.21	5.2	(GM)s	Silty Gravel with sand
	OD	54	23	58.64	23.54	6.03	10.19	(GM)s	Silty Gravel with sand
TS10-1	AR	59	23	59.58	20.79	10.46	9.16	(GM)s	Silty Gravel with sand
	AD	58	26	52.67	25.15	11.46	10.72	(GM)s	Silty Gravel with sand
	OD	50	17	53.25	27.49	10.84	8.41	(GM)s	Silty Gravel with sand
TS11-1	AR	57	16	41.97	18.9	16.44	16.8	(GM)s	Silty Gravel with sand
	AD	63	25	30.27	28.55	28.87	12.31	(GM)s	Silty Gravel with sand
	OD	56	26	32.96	31.54	21.77	13.73	(GM)s	Silty Gravel with sand
TS12-1	AR	57	22	55.98	26.94	8.05	9.02	(GM)s	Silty Gravel with sand
	AD	51	13	42.15	30.6	14.28	12.97	(GM)s	Silty Gravel with sand
	OD	49	15	46.24	35.87	8.39	9.51	(GM)s	Silty Gravel with sand
TS13-1	AR	57	17	46.02	22.03	14.85	17.1	(GM)s	Silty Gravel with sand
	AD	55	21	37.52	34.58	18.65	9.25	(GM)s	Silty Gravel with sand
	OD	49	16	38.07	38.83	18.2	4.9	(SM)g	Silty Sand with gravel
TS13-2	AR	53	18	64.43	17.56	6.01	4.22	GP-GM	Poorly-graded gravel with silt
	AD	55	20	58.52	19.67	11.24	7.74	(GM)s	Silty Gravel with sand
	OD	54	21	53.49	22.25	13.57	4.84	(GM)s	Silty Gravel with sand
TS14-1	AR	57	20	50.73	36.65	7.53	5.09	(GM)s	Silty Gravel with sand
	AD	55	22	58.76	23.62	7.9	9.71	(GM)s	Silty Gravel with sand
	OD	49	15	59.33	26.73	7.36	6.58	(GM)s	Silty Gravel with sand
TS14-2	AR	53	15	77.24	15.88	5.6	1.28	GP-GM	Poorly-graded gravel with silt
	AD	51	15	71.3	15.04	7	4.85	GP-GM	Poorly-graded gravel with silt
	OD	51	18	73.8	17.01	4.5	4.69	GP-GM	Poorly-graded gravel with silt
TS14-3	AR	57	24	63.95	8.11	2.83	4.24	GW-GM	Well-graded gravel with silt
	AD	51	19	72.13	16.01	3.98	2.94	GP-GM	Poorly-graded gravel with silt
	OD	46	14	68.66	19.21	4.75	2.67	GP-GM	Poorly-graded gravel with silt
TS15-1	AR	58	19	57.33	22.29	9.68	10.69	(GM)s	Silty Gravel with sand
	AD	54	22	49.86	26.32	13.11	10.71	(GM)s	Silty Gravel with sand
	OD	53	20	55.44	23.37	10.8	10.39	(GM)s	Silty Gravel with sand
TS16-1	AR	59	24	63.23	18.91	5.58	5.93	GP-GM	Poorly-graded gravel with silt
	AD	47	14	51.62	28.65	9.4	10.33	(GM)s	Silty Gravel with sand
	OD	54	20	51.16	27.38	10.11	11.35	(GM)s	Silty Gravel with sand

For the soils under investigation the grain-size analysis of the entire samples revealed that less than 50% from each samples of the soil passes the No. 200 sieve; hence, the soils are classified as coarse grained soils and the first letter will be G or S, i.e. G for gravels and S for sands. For sands and gravels the second letter of the classification is based on gradation for clean sands and gravels and plasticity of the fines for sands and gravels with fines. Hence, by making use of gradation of the soil sample and plasticity of the fines, which is shown in Table 4.15 above, the grouping of the soils for the as-received, air-dried and oven-dried pretreatment conditions have been made and summarized in the table 4.15.

As can be seen in Figure 4.16, Figure 4.17 and Table 4.15 above the soils under investigation fall in the MH zone of the USCS. Many residual soils rich in allophone or Kaolinite plot in the MH group (Blight, 1997) and according to the standard ‘guides’ used with the USCS these soils have ‘poor’ engineering properties and are considered unsuitable for road construction purposes. However, in practice, such soils frequently have good engineering properties especially for construction of sub grades and embankments. The classification of residual soils, especially those found in tropics, using the Unified Soil Classification System (USCS) has long been questioned (Blight, 1997). It was also discussed by Chen & Liew (2003) that the Unified Soil Classification System [ASTM D 2487-93] shall be used for virtually all geotechnical engineering work other than roads and highways construction.

Hence, for the case of soils found in western part of Ethiopia (Nedjo-Jarso-Begi areas) it is found that the USCS shall not be used for classifying the soils for road construction purpose. It appears that the most practical way to overcome this problem is to give the mineralogical composition of the soil together with its classification according to the USCS.

4.2.2.3 AASHTO Classification System

Different Authors used different classification techniques to classify residual tropical soils; Wesley L.D. and Irfan T.Y. Blight (1997) classify these soils based on the mineralogical composition and soil micro- and macrostructure; while, D’Hoor (1964) in Lyon Association (1971) classifies residual soils based on soil forming factors. It is also stated in Lyon Associates (1971) that the AASHTO classification system is convenient as the bases for classifying residual soils. The soils in this thesis work were also classified according to the AASHTO Classification System [AASHTO M-145], and summarized in Table 4.18 below. The soil used for the classification purpose was under as-received, air-dried and oven-dried pre-treatment conditions.

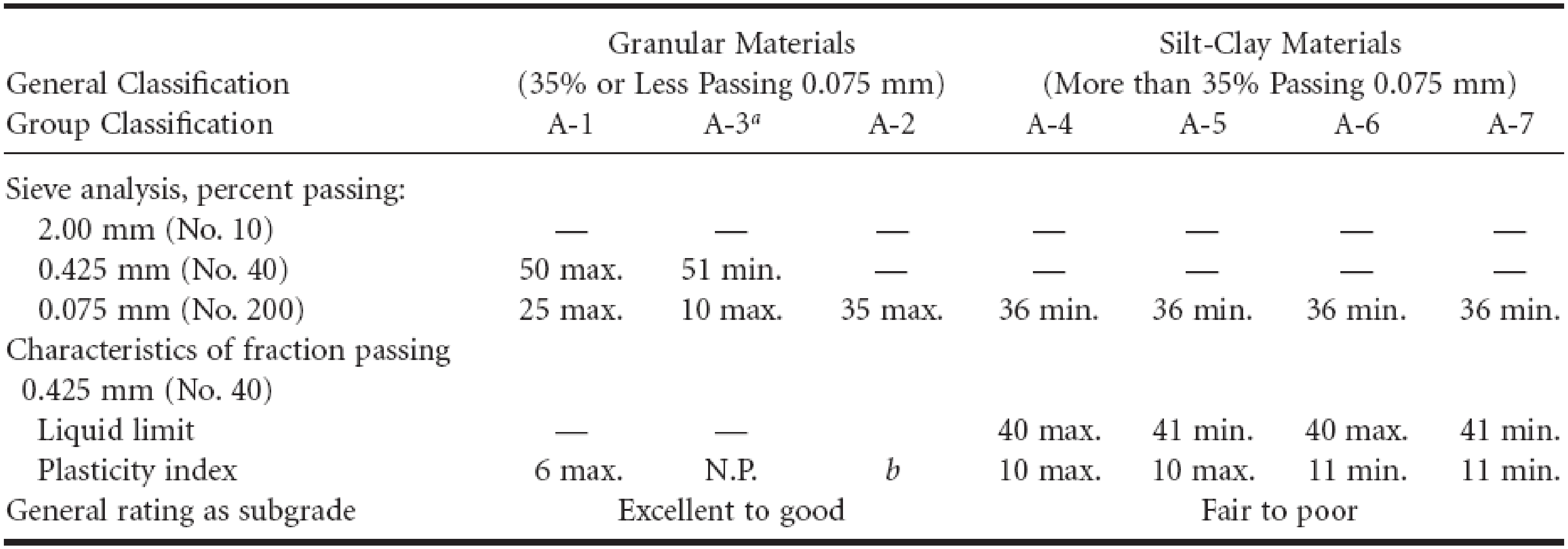
The AASHTO system classifies soils into seven primary groups, named A-1 through A-7, based on their relative expected quality for road embankments, sub grades, sub bases, and bases. Some of the groups are in turn divided into subgroups, such as A-1-a and A-1-b. Furthermore, a group index may be calculated to quantify a soil's expected performance within a group.

To determine a soil's classification in the AASHTO system, one first determines the relative proportions of gravel, coarse sand, fine sand, and silt-clay. In the AASHTO system gravel is material smaller than 75 mm (3 in.) but retained on a No. 10 sieve; coarse sand is material passing a No. 10 sieve but retained on a No. 40 sieve; and fine sand is material passing a No. 40 sieve but retained on a No. 200 sieve. Material passing the No. 200 sieve is silt-clay and is classified based on Atterberg limits. It should be noted that the division between gravel and sand is made at a smaller size (No. 10 sieve) in the AASHTO system than in the unified system (No. 4 sieve). Secondly, if any fines are present, Atterberg limits are determined and the plasticity index is calculated.

A soil is a granular material if less than 35% of the soil by weight passes the No. 200 sieve. Granular materials are classified into groups A-1 through A-3. Soils having more than 35% passing the No. 200 sieve are silt-clay and fall in groups A-4 through A-7.

Having the proportions of the components and the plasticity data, one uses one of the two alternatives AASHTO classification tables (Tables 4.16 & 4.17) and checks from left to right until a classification is found for which the soil meets the criteria. It should be noted that, in this scheme, group A-3 is checked before A-2. The AASHTO plasticity criteria are also illustrated in Figure 4.18.

Table 4.16 Classification of Soils and Soil-Aggregate Mixtures by the AASHTO System (AASHTO, 1990)



General Classification	Granular Materials (35% or Less Passing 0.075 mm)			Silt-Clay Materials (More than 35% Passing 0.075 mm)			
Group Classification	A-1	A-3[a]	A-2	A-4	A-5	A-6	A-7
Sieve analysis, percent passing:							
2.00 mm (No. 10)	—	—	—	—	—	—	—
0.425 mm (No. 40)	50 max.	51 min.	—	—	—	—	—
0.075 mm (No. 200)	25 max.	10 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing 0.425 mm (No. 40)							
Liquid limit	—	—		40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.	N.P.	*b*	10 max.	10 max.	11 min.	11 min.
General rating as subgrade	Excellent to good			Fair to poor			

[a] The placing of A-3 before A-2 is necessary in the “left to right elimination process” and does not indicate superiority of A-3 over A-2.

[b] See Table 4.17 for values.

Soils classified as A-1 are typically well-graded mixtures of gravel, coarse sand, and fine sand. Soils in subgroup A-1-a contain more gravel whereas those in A-1-b contain more sand. Soils in group A-3 are typically fine sands that may contain small amounts of non-plastic silt. Group A-2 contains a wide variety of “borderline” granular materials that do not meet the criteria for groups A-1 or A-3.

Soils in group A-4 are silty soils, whereas those in group A-5 are high-plasticity elastic silt. Soils in group A-6 are typically lean clays, and those in group A-7 are typically highly plastic clays.

Within groups containing fines, one may calculate a group index to further evaluate relative quality and supporting value of a material as sub grade. The group index is calculated according to the following empirical formula:

$$\text{Group index} = (F - 35)[0.2 + 0.005(LL - 40)] + 0.01(F - 15)(PI - 10) \text{……..Eq. 4.9}$$

In this equation F is the percentage of fines (passing the No. 200 sieve) expressed as a whole number. When calculating the group index for A-2-6 and A-2-7, only the PI term is used. The group index is rounded to the nearest whole number and, if negative, it is taken as zero. The expected performance is inversely related to group index. A value of zero indicates a good sub-grade material and a value above 20 indicates a very poor material.

Table 4.17 Classification of Soils and Soil-Aggregate Mixtures (AASHTO, 1990)

General Classification	Granular Materials (35% or Less Passing 0.075 mm)							Silt-Clay Materials (More than 35% Passing 0.075 mm)			
	A-1			A-2							A-7
Group Classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5, A-7-6
Sieve analysis, percent passing:											
2.00 mm (No. 10)	50 max.	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
0.075 mm (No. 200)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid limit	—		—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.[a]
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

[a] Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30.

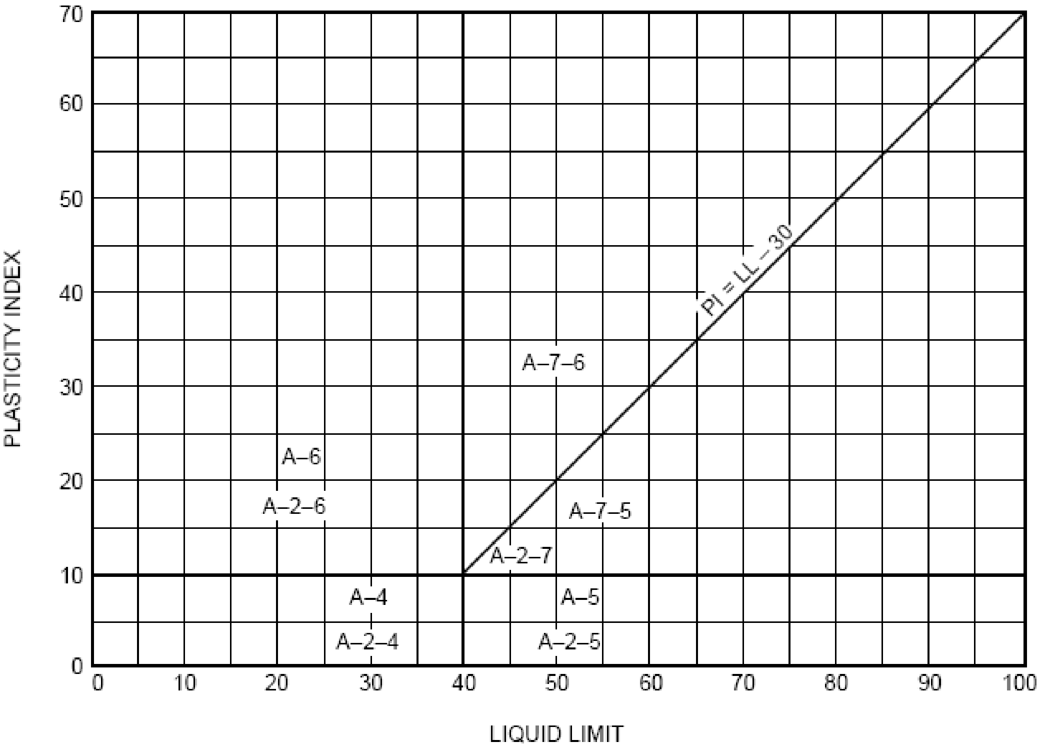


Figure 4.18 Plasticity chart for AASHTO Classification System (AASHTO, 1990)

As discussed in the above, the AASHTO system classifies soils into seven primary groups, named A-1 through A-7, and some of the groups are in turn divided into subgroups, such as A-1-a and A-1-b, based on their relative expected quality for road embankments, sub grades, sub bases, and bases. Furthermore, a group index may be calculated to quantify a soil's expected performance within a group. According to this classification system, it can be seen in Table 4.18, majority of the soils sampled from Nedjo-Jarso-Begi areas are fallen under subgroup A-2-7 with group index less than 4 and few samples are fallen under subgroup A-7-5 and A-7-6 with group index less than 15.

Generally a group index (GI) value of zero indicates a good sub-grade and embankment material and a value above 20 indicates a very poor material. For the case of the soils under investigation one can see that the soils can be considered as a good source of construction material as the majority of the soils sampled are fallen under subgroup A-2-7 with group index less than 4.

Table 4.18 Classification of soil samples according to AASHTO Classification Method

Sample design.	Sample Pre-treatment	Liquid Limit, LL (%)	Plasticity Index, PI (%)	Percentage passing of			Classification According to AASHTO	
				2.00-mm sieve	*0.425-mm sieve*	*0.075-mm sieve*	Group	Group Index
TS1-1	AR	56	20	48	41	34	A-2-7	2
	AD	56	22	56	47	41	A-7-5	5
	OD	47	17	38	27	20	A-2-7	0
TS1-2	AR	57	23	25	21	15	A-2-7	0
	AD	56	26	30	26	20	A-2-7	1
	OD	53	29	29	23	20	A-2-7	1
TS2-1	AR	55	19	21	17	14	A-2-7	0
	AD	61	26	32	25	20	A-2-7	1
	OD	54	22	29	21	17	A-2-7	0
TS2-2	AR	56	22	27	22	16	A-2-7	0
	AD	58	24	31	26	20	A-2-7	1
	OD	58	25	29	22	14	A-2-7	0
TS3-1	AR	56	19	25	23	20	A-2-7	0
	AD	57	22	33	28	21	A-2-7	1
	OD	49	16	39	33	27	A-2-7	1
TS3-2	AR	61	24	46	36	27	A-2-7	2
	AD	59	23	47	41	35	A-2-7	3
	OD	60	28	46	34	24	A-2-7	2
TS4-1	AR	55	18	51	47	43	A-7-5	4
	AD	57	20	51	41	30	A-2-7	2
	OD	53	20	46	42	38	A-7-5	3
TS4-2	AR	55	21	11	10	9	A-2-7	0
	AD	58	21	25	22	19	A-2-7	0
	OD	57	25	23	17	15	A-2-7	0
TS5-1	AR	56	21	48	41	35	A-2-7	2
	AD	54	22	50	44	36	A-7-5	3
	OD	53	19	44	39	32	A-2-7	2
TS5-2	AR	57	21	27	24	21	A-2-7	1
	AD	54	19	24	20	17	A-2-7	0
	OD	51	17	16	12	10	A-2-7	0
TS5-3	AR	61	24	22	19	15	A-2-7	0
	AD	60	24	35	29	24	A-2-7	1
	OD	52	20	25	19	16	A-2-7	0
TS6-1	AR	54	17	19	14	10	A-2-7	0
	AD	56	25	29	24	19	A-2-7	1
	OD	48	14	26	20	15	A-2-7	0
TS6-2	AR	58	26	36	26	18	A-2-7	0
	AD	52	20	35	28	21	A-2-7	1
	OD	54	22	20	17	14	A-2-7	0
TS7-1	AR	56	15	32	28	24	A-2-7	0
	AD	62	23	40	33	27	A-2-7	2
	OD	57	25	36	31	24	A-2-7	1

Classification of soil samples according to AASHTO Classification Method (Continued)

Sample design.	Sample Pre-treatment	Liquid Limit, LL (%)	Plasticity Index, PI (%)	Percentage passing of			Classification According to AASHTO	
				2.00-mm sieve	*0.425-mm sieve*	*0.075-mm sieve*	Group	Group Index
TS7-2	AR	56	22	26	23	20	A-2-7	1
	AD	57	16	29	25	22	A-2-7	0
	OD	62	28	30	24	19	A-2-7	1
TS8-1	AR	59	26	24	20	17	A-2-7	0
	AD	57	28	29	24	18	A-2-7	1
	OD	53	19	18	15	15	A-2-7	0
TS8-2	AR	59	24	22	19	16	A-2-7	0
	AD	54	23	30	24	19	A-2-7	1
	OD	50	18	30	19	14	A-2-7	0
TS9-1	AR	57	20	54	47	39	A-7-5	4
	AD	62	28	62	53	42	A-7-6	7
	OD	62	30	59	55	52	A-7-5	13
TS9-2	AR	59	21	14	10	8	A-2-7	0
	AD	55	22	22	16	13	A-2-7	0
	OD	54	23	23	19	16	A-2-7	0
TS10-1	AR	59	23	25	22	20	A-2-7	1
	AD	58	26	31	27	22	A-2-7	1
	OD	50	17	29	23	19	A-2-7	0
TS11-1	AR	57	16	42	37	33	A-2-7	1
	AD	63	25	55	47	41	A-7-5	6
	OD	56	26	52	42	35	A-2-7	3
TS12-1	AR	57	22	24	20	17	A-2-7	0
	AD	51	13	36	32	27	A-2-7	0
	OD	49	15	30	24	18	A-2-7	0
TS13-1	AR	57	17	42	37	32	A-2-7	1
	AD	55	21	48	37	28	A-2-7	1
	OD	49	16	45	31	23	A-2-7	0
TS13-2	AR	53	18	14	12	10	A-2-7	0
	AD	55	20	27	23	19	A-2-7	0
	OD	54	21	28	22	18	A-2-7	0
TS14-1	AR	57	20	28	15	13	A-2-7	0
	AD	55	22	24	21	18	A-2-7	0
	OD	49	15	25	18	14	A-2-7	0
TS14-2	AR	53	15	13	9	7	A-2-7	0
	AD	51	15	15	14	12	A-2-7	0
	OD	51	18	16	12	9	A-2-7	0
TS14-3	AR	57	24	10	8	7	A-2-7	0
	AD	51	19	13	10	7	A-2-7	0
	OD	46	14	16	9	7	A-2-7	0
TS15-1	AR	58	19	28	24	20	A-2-7	0
	AD	54	22	32	26	24	A-2-7	1
	OD	53	20	28	24	21	A-2-7	1
TS16-1	AR	59	24	17	14	12	A-2-7	0
	AD	47	14	31	25	20	A-2-7	0
	OD	54	20	32	26	21	A-2-7	1

4.2.2.4 Soil grouping based on mineralogical composition

As discussed in section 2.3.2 Wesley L.D. and Irfan T.Y. in Blight (1997) proposed a practical system for classifying all residual soils, based on the mineralogical composition and soil micro- and macrostructure. Wesley's classification system is intended to provide an orderly division of residual soils in to groups which belong together because of common factors in their formation and/or composition which can be expected to give them similar engineering properties.

Mineralogical identification using XRD analysis method and geochemical test results using X-Ray Fluorescent (XRF) analysis method reveal that the soils under investigation are composed of Kaolinite, Quartz, Hematite, Vermiculite, Illite, Borax, Dickite, and Nacrite. As can be seen from the geochemical analyses the soils do have a great concentration of sesquioxide of Aluminium and Iron. Hence, Soils of Nedjo, Jarso and Begi area are grouped under sub group c of group C; soils with a strong mineralogical influence deriving from special clay minerals only found in residual soils (i.e. based on the silicate clay minerals, halloysite and allophone, and non-silicate minerals ('oxide' minerals) which are the hydrated forms of aluminium and iron oxide (the sesquioxides), gibbsite and goethite) (Blight, 1997).

4.2.2.5 Soil grouping based on their genetic basis and soil forming factors

During recent studies, it was found that most of the tropically weathered soils of Africa could be divided into three groups based on a genetic basis and soil-forming factors. These groups are ferruginous soils, ferrallitic soils and Ferrisols as defined by D'hoore (1964) in Lyon Associates (1971). Climate is the most important factor in formation of the various soil groups. Parent material, topography, vegetables, drainage conditions and time character of parent rock are also factors and these may cause local modifications within each soil group (Lyon Associates, 1971).

The soils under investigation are formed over basaltic and metamorphosed types of rocks in intermediate to high rainfall areas where erosion has kept the pace with profile development. Geochemical tests (XRF analysis) and mineralogical tests (XRD analysis) show that the entire clay fraction comprises kaolinite, which predominates minerals of

Montmorillonite (Smeictite group), and Oxides of Iron and Aluminum as erosion has kept pace with profile development.

According to the prevailing soil forming factors and genetic basis, the soils under investigation, Nedjo, Jarso and Begi area, are fallen under a Ferrisol group.

4.2.3 Geochemical and Mineralogical tests

4.2.3.1 Geochemical Tests

Geochemical (oxide) tests are carried out to know quantitatively main oxides of the soil material. Almost all soils on earth contain some amount of colloidal oxides and hydroxides. The oxides and hydroxides of aluminium, iron and silicon are of greatest interest since they are the ones most frequently encountered. Iron and Aluminium oxides coat mineral particles, or cement particles of soils together. They may also occur as distinct crystalline units, such as hematite, gibbsite and magnetite (Dibsa, 2008; Tibebu, 2008).

For this thesis work, the geochemical tests were carried out at Geological Survey of Ethiopia Geochemical Laboratory using X-Ray Fluorescent (XRF) analysis method in order to obtain the percentage of oxide composition of the soils under investigation. The summary of test results is shown in Table 4.19.

In section 2.1.1 it is discussed that the degree of laterization of the soil samples can be evaluated based on Silica/Sesquioxides (S-S) ratio. The Sesquioxide, designated as R_2O_3, is the combination of aluminium oxide (Al_2O_3) and Iron oxide (Fe_2O_3). The chemical formula SiO_2 designates the silica. Accordingly soils having an s-s ratio greater than 2 are non-lateritic tropically weathered soils. For lateritic soils s-s ratio lies between 1.33 and 2 and for those of true laterites/laterites the ratio is less than 1.33. Lateritic soils have not under gone a considerable degree of laterization as compared to true laterites.

From the test results as shown in Table 4.19 the soils under investigation have Silica/Sesquioxide ratio below 1.33. This indicates that the soils under investigation are all true laterites. This is in agreement with soil forming factors of Nedjo - Jarso – Begi area which leads to laterites as pointed out in section 3.6. True laterites (S-S < 1.33) are simply referred as laterites. The soils of such kind are highly laterized, i.e. sesquioxides content are high.

Table 4.19 Oxide composition in percent (XRF analysis results)

Sample Location		***Sample Design.***	***%-age of Oxides (%)***														***Sio_2 / $Al_2O_3+Fe_2O_3$***	***Remark***
Station, Offset	***Depth***		***Sio_2***	***Al_2O_3***	***Fe_2O_3***	***CaO***	***MgO***	***Na_2O***	***K_2O***	***TiO_2***	***P_2O_5***	***MnO***	***SO_3***	***Cr_2O_3***	***LOI***	***H_2O***		
35+980, 120m RHS	0.6m	TS5-1	35.24	28.77	16.20	0.14	0.47	0.05	0.22	3.131	0.467	0.107	0.07	0.041	13.05	1.72	***0.78***	True laterites (Ratio < 1.3)
35+980, 120m RHS	1.8m	TS5-2	*33.04*	*29.94*	*18.35*	*0.08*	*0.30*	*0.06*	*0.08*	*3.143*	*0.527*	*0.112*	*0.02*	*0.04*	*12.57*	*1.47*	***0.68***	
44+080, 40m LHS	1.0m	TS6-1	32.73	26.23	21.23	0.14	0.49	0.07	0.23	2.138	0.486	0.054	0.05	0.047	14.32	*1.52*	***0.69***	
44+080, 40m LHS	2.0m	TS6-2	32.21	30.07	17.77	0.11	0.31	0.06	0.18	2.531	0.475	0.056	0.02	0.056	14.00	*1.84*	***0.67***	
53+000, 40m RHS	1.5m	TS8-1	*32.15*	28.95	20.39	0.07	0.38	<0.01	0.17	2.242	0.36	0.041	0.02	0.049	13.26	1.62	***0.65***	
70+040, 300m RHS	1.5m	TS12-1	31.40	31.14	18.51	0.04	0.25	<0.01	0.12	2.858	0.319	0.110	0.02	0.016	13.89	1.05	***0.63***	

4.2.3.2 Mineralogical Tests

Mineralogy controls the sizes, shape, and surface characteristic of the particles in the soil. Physical and engineering properties of soils are also being controlled by mineralogy. These features along with interaction with the fluid phase determine plasticity, swelling, compression strength and hydraulic conductivity behavior. Thus, mineralogical composition (together with structure) is an important factor that is fundamental to the understanding of geotechnical engineering characteristics of residual soils.

The most widely used technique to determine mineralogical composition is X-Ray Diffraction (XRD) analysis method. For this thesis work, the method that is the XRD analysis was conducted at Ethiopian Geological Survey, Mineralogy and Petrography Laboratory by powder diffraction method after grinding the soil samples without separating the clay fraction. The results of analysis are shown in Table 4.20.

Table 4.20 Mineralogical test results (XRD analysis results)

Sample Location		***Sample Design.***	***Minerals***	***Chemical Formula***
Station, offset	***Depth***			
35+980, 120m RHS	0.6m	TS5-1	Kaolinite	$Al_4(OH)_8(Si_4O_{10})$
			Quartz	SiO_2
			Hematite	Fe_2O_3
			Vermiculite	$Mg_3Si_4O_{10}(OH)_2$
35+980, 120m RHS	1.8m	TS5-2	Kaolinite	$Al_4(OH)_8(Si_4O_{10})$
			Quartz	SiO_2
			Hematite	Fe_2O_3
			Vermiculite	$Mg_3Si_4O_{10}(OH)_2$
44+080, 40m LHS	1.0m	TS6-1	Kaolinite	$Al_4(OH)_8(Si_4O_{10})$
			Quartz	SiO_2
			Dickite	$Al_2(Si_2O_5)(OH)_4(HCONH_2)$
44+080, 40m LHS	2.0m	TS6-2	Kaolinite	$Al_4(OH)_8(Si_4O_{10})$
			Quartz	SiO_2
			Borax	$Na_2B_4O_5(OH)_4(H2O)_8$
			Dickite	$Al_2(Si_2O_5)(OH)_4$
53+000, 40m RHS	1.5m	TS8-1	Kaolinite	$Al_4(OH)_8(Si_4O_{10})$
			Quartz	SiO_2
			Hematite	Fe_2O_3
			Illite	$K_{0.5}(Al,Fe,Mg)_3(Si,Al)_4O_{10}(OH)_2$
			Nacrite	$Al_2(Si_2O_5)(OH)_4$
70+040, 300m RHS	1.5m	TS12-1	Kaolinite	$Al_4(OH)_8(Si_4O_{10})$
			Quartz	SiO_2
			Borax	$Na_2B_4O_5(OH)_4(H2O)_8$
			Nacrite	$Al_2(Si_2O_5)(OH)_4$

5. Comparisons and discussions

5.1 Comparison of test results with other lateritic soils

Laterites and Lateritic soils of Africa were studied by Morin W.J. and Todor P.C. (Lyon Associates, 1971). During the study, soil samples were collected from different parts of Africa such as Ghana, Ethiopia, Kenya, Uganda etc. The characteristics and mineral contents of the soils taken from Ethiopia were studied as ferrisols.

Comparison was made for the Western Ethiopia lateritic soils with known laterites and lateritic soils of Africa using Index property test results. It was found that during a study by Lyon Associates (1971) that most of the tropically weathered soils of Africa were divided into three distinct groups: namely ferruginous, ferrallitic soils and ferrisols. The results of index property tests of these soils with the lateritic soils of Western Ethiopia are tabulated in Tables 5.1 to 5.4.

The typical soil index properties, i.e., liquid limit, plasticity index, gradations, of the tropically weathered soils of Africa and Western Ethiopia lateritic soils are shown in Tables 5.1 to 5.4.

The ferruginous soils are lower in plasticity than the other two groups. The ferrallitic soils are similar, to some extent, to the ferrisols, exhibiting higher plasticity than ferruginous soils. There are major differences between soils of the ferruginous group and the soils of the ferrallitic and ferrisols groups. The data indicate that there is an apparent similarity in the physical properties of the ferrallitic and ferrisols soil groups. The major mineralogy of tropically weathered African soils and Western Ethiopia lateritic soils is shown in Table 5.5 for the three soil sub groups of tropically weathered soils of African and western Ethiopia soils. From the table one can see that the three soils sub groups differ in major mineralogical composition as discussed in Lyon Associates (1971).

The Western Ethiopia lateritic soils upon comparison with previously tested laterites and lateritic soils of Africa are similar, to some extent, to ferrisol and ferralitic soil sub groups with respect to index test results and mineralogical composition of the soils which are shown in Tables 5.2 to 5.6. The data indicates that there is higher plasticity similar to ferrisol and ferralitic soil sub groups.

When comparison is made on the average index test properties of the three sub group of African laterites /lateritic soils/ and the Western Ethiopia lateritic soils which is summarized in Table 5.6, the gradation and Atterberg limits are nearly similar for both Western Ethiopia lateritic soils and those of Ferrisols of Africa excluding Ghana.

Table 5.1 Typical soil index test results for Ferruginous soils (Lyon Associates, 1971)

Country	AASHO	GI	LL (%)	PL (%)	PI (%)	25 mm	19 mm	9.5 mm	4.75 mm	2.00 mm	0.425 mm	0.075 mm
Ghana	A-2-6	0	26	15	11						45	20
Senegal	A-2-7	0	39	20	19	95	91	68	46	33	27	20
Upper Volta	A-2-6	1	38	14	24	100	97	80	66	51	38	25
Niger	A-2-4	0	21	11	10	97	89	73	64	55	40	25
Tanzania	A-2-6	6	34	19	15	100	100	100	100	100	93	61
Kenya	A-2-7	0	45	31	14	100	100	94	88	52	40	28
Uganda	A-2-6	2	38	17	22	100	100	96	83	61	51	34
Sudan	A-2-4	0	21	12	9	100	100	100	100	98	57	27
Gambia	A-2-6	0	36	16	20	98	77	53	42	34	28	22

Table 5.2 Typical soil index test results for Ferrallitic soils (Lyon Associates, 1971)

Country	AASHO	GI	LL (%)	PL (%)	PI (%)	25 mm	19 mm	9.5 mm	4.75 mm	2.00 mm	0.425 mm	0.075 mm
Ghana	A-6	6	38	18	20	100	100	100	95	81	67	47
Liberia	A-2-7	2	56	29	27	100	95	72	57	41	36	27
Gabon	A-2-4	0	35	18	17							
Sierra Leone	A-2-6	1	55	31	24	100	98	90	68	37	29	27
Burundi	A-6		31	16	16	100	100	92	84	76	74	70
Dahomey	A-2-7	4	45	21	24	100	100	99	85	72	55	39
Ivory Cost	A-7-6	22	62	31	31	100	100	100	100	99	88	69
Mali	A-6	3	35	21	14	100	100	89	67	55	51	40
Uganda	A-6	2	39	19	20	100	100	91	82	73	53	38

Table 5.3 Typical soil index test results for Ferrisols soils (Lyon Associates, 1971)

Country	AASHO	GI	LL (%)	PL (%)	PI (%)	25 mm	19 mm	9.5 mm	4.75 mm	2.00 mm	0.425 mm	0.075 mm
Ghana	A-7-5	3	53	34	19						50	37
Niger	A-2-6	0	28	16	12	100	100	98	82	68	39	26
Ivory Cost	A-7-6	18	48	24	24	100	99	83	65	60	50	40
Mali	A-7-5	3	55	31	24	100	100	89	61	51	43	38
Uganda	A-2-7	0	46	21	25	100	100	91	56	31	24	20
Kenya	A-7-5	27				100	100	100	100	99	98	91
Cameron	A-7-5	19	65	37	27	100	100	100	98	97	88	66
Ethiopia	A-7-5	19	68	33	35	100	100	98	84	63	62	58
Ghana	A-7-6	12	57	25	32	100	100				65	50

Table 5.4 Typical Index test results for Western Ethiopia lateritic soils

Area	AASHTO	GI	LL (%)	PL (%)	PI (%)	25 mm	19 mm	9.5 mm	4.75 mm	2.00 mm	0.425 mm	0.075 mm
Nedjo-Mendi	A-2-7	0	56	36	20	88	77	59	43	26	19	13
Nedjo-Mendi	A-2-7	0	56	38	18	97	84	49	32	21	17	14
Nedjo-Mendi	A-7-5	18	59	39	20					100	85	76
Nedjo-Mendi	A-2-7	0	59	37	22	94	90	68	52	34	28	24
Nedjo-Mendi	A-2-7	0	67	43	24	96	90	75	57	37	31	26
Nedjo-Mendi	A-2-7	0	54	34	20	83	69	46	33	22	17	15
Nedjo-Jarso-Begi	A-7-5	5	56	34	22	100	98	86	69	56	47	41
Nedjo-Jarso-Begi	A-2-7	3	59	36	23	100	98	89	73	47	41	35
Nedjo-Jarso-Begi	A-2-7	1	56	31	25	96	88	52	36	29	24	19
Nedjo-Jarso-Begi	A-2-7	1	54	32	22	94	90	65	37	22	16	13
Nedjo-Jarso-Begi	A-2-7	0	55	35	20	88	80	54	39	27	23	19
Nedjo-Jarso-Begi	A-2-7	0	55	33	22	99	95	72	50	32	26	24

Table 5.5 Major mineralogy of tropically weathered African soils and Western Ethiopia lateritic soils

Ferruginous	Ferrallitic	Ferrisols	Western Ethiopia soils
Hematite	Gibbsite	Kaolinite (predominant)	Kaolinite (predominant)
Goethite	Goethite	Goethite	Quartz
Kaolinite	Kaolinite	Hematite	Hematite
Organic matter (absent to sparse)	Organic matter (sparse to abundant)	Gibbsite (less common) Organic matter (sparse to abundant)	Vermiculite, Dickite Nacrite and Gibbsite Organic matter (sparse to abundant)

Table 5.5 Average soil properties

Type of Test		Ferruginous		Ferrallitic		Ferrisols		Nedjo-Mendi soils	Nedjo-Jarso-Begi soils
		Ghana	Other African Countries	Ghana	Other African Countries	Ghana	Other African Countries		
GRADATION	Sieve size (mm)	Percentage passing (%)							
	25 mm	99	99	99	99	95	99	95	94
	19 mm	98	98	96	97	94	99	88	89
	9.5 mm	93	89	86	90	86	92	73	70
	4.75 mm	75	76	70	80	73	74	63	51
	2.00 mm	51	65	54	70	52	61	52	35
	0.425 mm	46	51	46	54	40	51	45	29
	0.075 mm	30	32	34	40	37	44	38	24
	0.002 mm	13	16	19	26	25	24	9	8
PLASTICITY	Limits	Atterberg limits							
	LL	31	33	42	47	46	55	59	56
	PL	18	12	24	24	23	29	38	34
	PI	14	15	19	23	23	27	22	22

5.2 Comparison of test results of previous researches

Some of the engineering properties of lateritic soils of Western Ethiopia have been studied by different researchers, such as Zelalem (2005) has studied on lateritic soils found in Nedjo-Mendi areas; Wakuma (2007), Kebede (2008) and G/medhin (2008) have studied on Assosa lateritic soils; and Dibisa (2008) has studied soils found in Nedjo, Mendi and Assosa areas. During their index property tests, they have used different sample pretreatments and testing procedures; and come out with the following results.

Comparison of moisture contents determined using conventional drying temperature (105^{o}C oven temperature) and air drying temperature (or 50^{o}C oven temperature) revealed that the lateritic soils found in Nedjo-Mendi area do not have loosely bound water of hydration (Zelalem, 2005); even though, Dibisa (2008) and G/medhin (2008) have found that the soils in Nedjo, Mendi and Assosa areas do have small amount of structural water or water of hydration. The lateritic soils found in Assosa contain a considerable amount of structural water or water of hydration (Wakuma, 2007).

In the comparison of Atterberg limits tests, the different pretreatments during sample preparations do have insignificant effect on Atterberg limits of Nedjo-Mendi area lateritic soils (Zelalem, 2005); eventhough, Dibisa (2008) has found that the different pretreatments during sample preparations affect the Atterberg limits of Nedjo, Mendi and Assosa area soils. Wakuma (2007) have also found that the soils found in Assosa have been affected by the different pretreatments during sample preparations. The soils of Nedjo-Mendi areas have been found susceptible to breakdown with manipulations or elongated mixing times during Atterberg limit tests (Zelalem, 2005). Wakuma (2007) also observed that the soils of Asossa are susceptible to manipulations or elongated mixing times. However, Dibisa (2008) has found that Nedjo, Mendi and Assosa areas soils are not susceptible to manipulations or elongated mixing times during Atterberg limit tests.

In gradation tests comparison, the different sample pretreatments and testing procedures have resulted negligible difference in grain-size analyses /or grading curves/ of Nedjo-Mendi area soils (Zelalem, 2005). In Wakuma (2007), Assosa soils have showed little difference on their gradation distribution curves for variations in pretreatments; however, the tests have showed ambiguous results for samples tested under oven-dried pretreatment condition during sample preparation. However, lateritic soils of Nedjo-Mendi-Assosa areas have highly affected by pre-test drying than remolding /or testing procedures/ (Dibisa, 2008).

Comparison of specific gravity tests showed that the specific gravity of Nedjo-Mendi area lateritic soils is significantly changed upon drying prior to testing (Zelalem, 2005). Wakuma (2007) has found that the specific gravity of Assosa soils have reduced strongly with higher pre-test oven drying temperatures; however, at lower pre-test drying tempratures the decrease is insignificant. Lateritic soils of Nedjo, Mendi and Assosa area have also showed decrease in the specific gravity upon oven drying temperatures (Dibisa, 2008).

In addition to the above comparision on studies which haven been done on Western Ethiopia lateritic soils, Tibebu (2008) has done an investigation on the index properties and shear strength parameters of laterite soils found in Southern part of Ethiopia (in the case of Wolayita-Sodo). In her investigation, the conventional drying temperature was too high for few samples during moisture content determination as the soils contained loosely bound water of hydration. From her investigation, the different pretreatments have slightly affect the Atterberg limits of the Wolayita-Sodo area lateritic soils even if the soils susceptiblity to breakdown with manipulations or elongated mixing times is limited to these soil samples prepared in air dry pretreatment conditions.

5.3 Discussions of test results and testing procedures

Soil samples were collected from Nedjo–Jarso-Begi road, which is located in South Western Ethiopia in Western Wellega Administrative zone of the Oromiya Regional State. The area is dominantly covered by basalt with minor granite/granodiorite, schist and recent alluvial deposits. The mean minimum and maximum annual temperature lies between 12-14^{o}C to 25-26^{o}C. The annual mean temperature is about 30^{o}C owing to its elevation, 1350 to 1500m above sea level. The mean annual rainfall varies from 1200mm to around 2000mm, i.e., the area lies in the medium to high rain fall with the average annual value around 1600mm. Significant rain can be expected in the area from the month of April to October, inclusive, with peaks around July and August. During the remainder of the year there is very little precipitation. The topography of the route corridor is almost all flat to rolling terrain from the beginning till the end of the project which favorable to the formation of lateritic soils. In Western Ethiopia, Wellega province along the line Nekempte–Gimbi–Nedjo–Mendi–Assossa; and Nedjo–Jarso–Begi road routes, the existing soil formation factors such as topography, temperature, rainfall, and parent rocks are favorable for laterites formation. By comparing the lateritic soil formation factors and the actual soil information of the research area with the supplement of previous researchers data western Ethiopia is highly covered with lateritic soils. This was proven by the geochemical and index tests of the soils.

From the comparison of index test results of previous researchers, it can be seen that there is a need of minimizing and reducing the discrepancy in test results of western Ethiopia lateritic soils. In order to overcome and minimize the discrepancy in testing results the need of investigation of the appropriate laboratory testing procedures is vital. Hence, the index properties of the Nedjo-Jarso-Begi areas have been studied using various testing procedures and pretreatment conditions in order to investigate the appropriate laboratory testing procedures of these red, highly weathered lateritic soils of western Ethiopia. In addition of soil samples from western Ethiopia two additional non lateritic soils from Addis Ababa were taken in order to compare the effects of different pretreatments and testing procedures on non lateritic soils. Index property tests have been carried out on the soil samples collected from the research area using various testing procedures and pretreatment conditions after the soil samples have been confirmed that they are lateritic soils using mineralogical and geochemical tests. Then, the sensitivity of the soils for various pretreatment conditions and testing procedures has been investigated using the test results.

Different drying temperatures were used in order to check the sensitivity of the soils to conventional drying temperature (105^{o}C oven temperature) in moisture content determination. The loss of water of hydration of the soil samples under investigation have been checked by carrying out the moisture content determination test using conventional drying temperature (105^{o}C oven temperature) and air drying temperature (or equivalently 50^{o}C oven temperature with maximum relative humidity, RH, of 30%). The difference in moisture contents between that of conventional oven temperatures of 105^{o}C and air drying temperature for all lateritic soils under investigation are below 4 %. However, comparing to the test results of the non lateritic soils from Addis Ababa around Entoto area which are nearly equal for both drying temperatures, the soils of Western Ethiopia do have slight amount of water of hydration. Hence, it is more appropriate to use lower drying temperature, say air drying (or equivalently 50°C oven temperature with maximum relative humidity, RH, of 30%) during moisture content determination of Western Ethiopia lateritic soils.

The effect of pretreatments on Atterberg limits were checked by conducting the tests on soil samples pretreated using an oven dry (105°C oven temperature), air dry (or equivalently 50°C oven temperature with maximum relative humidity, [5]RH, of 30%), and as-received (moist) pretreatments during sample preparations. The corresponding test results showed that the tests which were carried out under different pretreatment conditions prior to testing gave various results. Air and oven-drying soil specimens prior to carrying out the Atterberg limit tests, rather than testing at natural moisture content have resulted in a decrease in the liquid limit, plastic limit and to a lesser extent in the Plasticity Index of Western Ethiopia lateritic soils. From the test results and different literatures, it is observed that the laboratory pretreatments given for such lateritic soils should reflect the actual field conditions; hence, the test samples under investigation should not be pretreated using higher over drying tempratures as the soils will not experience such high temperatures in the field.

The effect of disaggregation of clay–size particles on Atterberg limit tests during test manipulation /mixing / were checked for soil samples under consideration. The liquid limits of the soils were determined using varying liquid limit testing methods. In the three pretreatment conditions the test results showed that the soils under investigation contains concretionary that will be broken down by elongated testing manipulation. That is, during test manipulation /mixing/ the aggregations between clay-size particles will be detached which result in higher value of liquid limits. As it is observed that some Western Ethiopia lateritic soils are sensitive to test procedures and the energy applied to the soil samples during Atterberg limits tests, the laboratory testing of these area soils shall be properly controlled in order to minimize the disaggregation of clay-size particles. Hence, the minimum mixing times usually of 5minutes and a fresh soil shall be used for each point on the plasticity tests.

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[5] RH as all tests were conducted in Addis Ababa and the City is located at high lands, there is no case that the relative humidity exceeds 30%.

From the test results, it was observed that the specific gravity of Western Ethiopia lateritic soils was reduced with increasing oven drying temperature from the in-situ condition. This is due to the dehydration and/or aggregation of clay particles of the lateritic soils upon drying at higher temperatures. Hence, it is essential that the specific gravity tests shall be done on the soil samples which are in their natural moisture content condition and pre-test drying of sample should be avoided; in addition to these, the dry mass of the soils used in the test should be calculated by drying the soil specimen after the specific gravity test has been completed at reduced temperature, i.e. air dried (or equivalently 50°C oven temperature with maximum relative humidity of 30%).

From the test results of the soil samples which were pretreated under three different pretreatment conditions namely oven-dried (OD), air-dried (AD) and as-received (AR) and tested under dry and wet testing procedures, it was observed that the air-dried (AD) and oven-dried (OD) pretreatments with dry testing procedures resulted in increasing the finer particles of the soil samples while the coarser particles are decreased in percentage than the wet sample pretreatments and testing procedures. The fraction of sand (in AD & OD samples), silt plus clay (in AD samples) were increased and the percentages of gravels were reduced in both AD & OD samples as the coarser particles became highly fractured during the pulverization process. From the test results, it is observed that the percentages of silts and clays were increased in the case of air-dried samples; however, it is nearly the same in the oven-dried samples, i.e. the oven-dried pretreatment conditions were resulted in small difference for the finer portion of gradation (i.e. for silts and clays). This may be, due to the fact that, when lateritic soils are oven-dried at high temperatures there is mineralogy alteration and/or development of larger capillary forces between particles; hence, the degree of attraction forces for fine particles become increased due to the cementation of sesquioxides. It is therefore observed that for Western Ethiopia lateritic soils the wet sieving method /testing procedures/ shall be used as the soils are sensitive to manipulation /pulverization/ and higher pretest temperatures.

The sensitivity of gradation and grading curves for variation in specific gravity within a sample were also checked using the specific gravities of fines and coarser fractions separately in grading analysis. Once the specific gravities fines and coarser fractions were made, the grading was calculated by volume proportions as well as by mass proportions. From the test results it was observed that the grading curves of the soils under investigation using mass and volume proportions is not vary significantly, especially for soil samples which were tested under wet testing method during the gradation tests. For the case of few pretreated soil samples (AD & OD samples) there is a slight difference in the grading curves, and the OD samples have showed higher difference than AD samples; however, majority of the soils under investigation do have nearly identical grading curves. Hence, for the soil samples under investigation it can be said that the need of modifying the grading curves using mass proportion is not as such important especially when wet sieving method is used.

During the classification of the soils using the Unified Soil Classification System (USCS), majority of Western Ethiopia lateritic soils fall under MH zone which indicates that the fines are elastic silts. According to the standard 'guides' used with the USCS these soils are considered unsuitable for road construction purposes. However, in practice, such soils frequently have good engineering properties especially in the construction of sub grades and embankments. For the case of lateritic soils found in Western Ethiopia (Nedjo-Jarso-Begi area), the justification of these soils is questioned. Hence, the use of USCS alone for classifying the Western Ethiopia lateritic soils for road construction purpose is not seems appropriate.

During classification of soils using the AASHTO classification system, it was observed that majority of the soils sampled from Nedjo-Jarso-Begi area are fallen under subgroup A-2-7 with group index less than 4 and few samples are fallen under subgroup A-7-5 and A-7-6 with group index less than 15. From the results of classification, it was obtained that the majority of the soils sampled are fallen under subgroup A-2-7 with group index less than 4 which indicate that these soils samples can be used as a good source of construction material. Hence, the AASHTO Classification System is more appropriate in classifying lateritic soils of Western Ethiopia than the USCS.

From the above discussions of index test results and testing procedures of the Western Ethiopia lateritic soils and non lateritic soils from Addis Ababa, it can be seen that the Western Ethiopia lateritic soils are very sensitive to the type of pretreatments and testing procedures. Hence, in order to overcome and minimize the discrepancy in index test results of these area soils, the use of the laboratory testing procedures which is attached in Appendix-A is very important as the soils found in Western Ethiopia have been investigated sensitive for various pretreatments and testing procedures.

6. Conclusions and recommendations

6.1 Conclusion

Based on the investigation of the index test results the soil samples of Nedjo-Jarso-Begi area, Western Ethiopia, the following conclusions can be drawn:

1. Geochemical test results indicate that the soils of Nedjo-Jarso-Begi areas are laterites having high concentration of iron oxide and/or aluminium oxide (sesquioxides). The degree of laterization, silica to sesquioxides ratio, is below 1.33.

2. The test results showed that the Western Ethiopia lateritic soils are sensitive to the temperature applied prior to testing. Some soils also contain structural water or water of hydration that could be driven off irreversibly when using oven drying of 105^{o}C. Hence air-drying or oven-drying of 50^{o}C with relative humidity (RH) of 30% should be used for every test during sample preparation.

3. It is observed that some Western Ethiopia lateritic soils are sensitive to test procedures and the energy applied to the soil samples during Atterberg limits tests; hence, the laboratory testing of these area soils shall be properly controlled in order to minimize the disaggregation of clay particles. Hence, during Atterberg limit tests, the minimum mixing time usually of 5minutes and a fresh soil shall be used for each point on the plasticity tests.

4. The Activity tests showed that, the soils of Western Ethiopia lateritic soils have activity number of less than 1.25. Similarly, the free swell tests showed an average free swell of less than 50% (i.e., the soils have Low Swell Potential). Therefore, Western Ethiopia lateritic soils are inactive as compared to the swelling characteristic of fine grained soil (clay soils).

5. The specific gravity test results are higher values than the temperate zone soil. This is due to high amount of iron oxide for soil under investigation. And, during specific gravity test avoid any form of pre-test drying in order to determine the dry mass of the soil rather obtain the dry mass after the test has been done using lower oven drying temperatures, 50^oC with relative humidity (RH) of 30%, as some Western Ethiopia lateritic soils have water of hydration or structural water which will be driven off by oven drying of 105oC or due to dehydration and/or aggregation of clay particles of the lateritic soils upon drying at higher temperatures.

6. In cases where the grading curves using mass proportions show gap graded and where the separate specific gravities of fine and coarse fractions of the soils differ largely, it is important to evaluate the grading curves of the lateritic soils by mass proportion and volume proportion using the separate specific gravities of fine and coarse fractions separately.

7. The AASHTO classification system can be applied as well with the lateritic soils of Western Ethiopia as it can with temperate zone soils. However, during the classification tests all the above pretreatment and testing procedures shall be practiced.

8. The Unified Soil Classification System is not appropriate for classifying the Western Ethiopia lateritic soils for road construction purpose.

9. During the determination of the index properties, i.e. moisture content test, plasticity tests (liquid limit, plastic limits and plasticity index), gradation and specific gravity tests, of the Western Ethiopia lateritic soils Appendix-A is given as guide /or somehow an appropriate testing procedures/ for the determination of the index properties of these type soils, soils which are sensitive to the pretreatment conditions and testing procedures.

6.2 Recommendations

- In order to use the Laterites which are widely distributed in western Ethiopia as materials in road construction proper selection criteria should be used. Until recently much of this use has been done using the inappropriate specification, such as those developed for the climatic conditions of Europe and North America. In this area, with the need for better roads carrying more traffic, there is an increasing requirement for good quality material for the upper pavement layers, much of which has to be imported or hauled long distances. The cheap and locally available materials, which are suitable for the upper pavement levels of low-volume roads, are often used insufficiently as sub-base, or even earth-fill, for busier roads. In order to reduce the wastage of a valuable resource, many tropical countries have prepared their own road specification, usually through their ministry of transport or highway department, rather than using temperate zone specification. Other countries use the recommended specifications developed by the highway research organizations of western countries, such as those of France and Britain. Therefore it is recommended that a further study or comparison be made on the different countries specification /selection criteria/ for the use laterites as road construction materials.

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APPENDIX – A

LABORATORY TESTING PROCEDURES

1. MOISTURE CONTENT TEST

General

The moisture or water content of a soil sample is an indicator of the amount of water present in soil. It is the ratio of the weight of water contained in the sample to the weight of solids in the sample, expressed in percentage.

$$\omega = \frac{W_w}{W_s} \times 100 \text{---} \quad \text{(A-1)}$$

Where ω = moisture content of soil (expressed as percentage)

W_w = weight of water in soil sample (i.e. initial weight of moist soil minus weight of oven dried soil)

W_s = weight of soil solids in sample

W_w and W_s may be expressed in any units of weight, but both should be expressed in the same unit.

Apparatus Required

- Balance (with accuracy to 0.01g)
- Oven (with accurate temperature control and temperature gage)
- Metal boxes/Containers (e.g., tin or aluminum moisture cans with lids)

Test sample

A representative sample of the moist soil to be tested should be taken in an amount as indicated in the Table A-1 below.

Table A- 1 Minimum Mass of moist sample (ASTM, 2004)

Maximum particle size (100% passing)	Standard sieve Size	Recommended minimum mass of moist test specimen for water content reported to ±0.1%	Recommended minimum mass of moist test specimen for water content reported to ±1%
2.0 mm or less	No. 10	20 g	20 g
4.75 mm	No. 4	100 g	20 g
9.5 mm	3/8-in.	500 g	50 g
19.0 mm	3/4-in.	2.5 kg	250 g
37.5 mm	1½-in.	10 kg	1 kg
75 mm	3-in.	50 kg	5 kg

Test Procedure

1) Weigh container with representative wet sample in accordance with Table A-1 to nearest 0.01 gram and record on data sheet
2) Uncover container and place in oven to dry (see Note 1.1 & 1.2)
3) Remove from oven, replace cover tightly, and set aside to cool to room temperature
4) Weigh container with dried sample to nearest 0.01 gram and record on data sheet
5) If tare weight is not already available, clean, dry and weigh container with cover to nearest 0.01 gram and record on data sheet (see Note 1.3)
6) Compute moisture content as shown on data sheet and in sample calculation using the above equation (Eq. A-1)

Note 1.1: Two test portions should be prepared for moisture-content determinations. One portion should be over-dried at 105°C until successive test weightings (greater than ½ hr.) show that no further weight loss is taking place or insignificant change (i.e., less than about 0.1%), and the moisture content should then be determined. The other portion should be air-dried or oven-dried at no more than 50°C with a maximum relative humidity (RH) of 30% until successive test weightings show no further weight loss, and the moisture content then determined. Then, the two test results should be compared; a significant difference (4 -6%) indicates that the material contains ‘structural water’ or ‘water of hydration’ which does not play a part in the field performance of the soil. If this is confirmed by repeat tests then the oven-drying temperatures for the subsequent programme of tests should be changed to air-drying or oven-drying with no more than 50°C.

Note 1.2: To air-dry the material, place it in pans or spread it on a canvas and expose it to direct rays of sun or to a draft (frequent agitation or stirring speeds up the drying process). In case of dry atmosphere, the material also dries readily inside the laboratory or in the shade. A fan blowing air over the sample greatly increases the rate of evaporation/drying.

Note 1.3: It is recommended that all containers used for moisture-content tests be numbered and their weights obtained in advance and recorded for reference.

Sample calculation

1. To calculate the weight of water in sample

Wt water = (wt wet sample + can) – (wt dry sample + can) = 152.89 - 115.69 = 37.20gm

2. To calculate the weight of dry sample

Wt dry sample= (wt dry sample + can) - (wt can) = 115.69 - 5.42 = 110.27gm

3. To calculate moisture content

Moisture content = 100 x wt water/ Wt dry sample =100 x 37.20/ 110.27 = 33.74%

Table A- 2 Moisture content test data sheet

DATA SHEET
Moisture-content Test

Sample name: TS1-1
Project area (No.): NJB Road
Depth: 0.6m
Location(station): 10+880, 1.5 km RHS
Description of sample: Reddish brown silty gravel
Tested by: W.M.
Date: 7/11/2008

Determination No.:	***1***	***2***	***3***
Container (can) no.	31		
Weight of can + moist soil, W_1(g)	152.89		
Weight of can + dry soil, W_2(g)	115.69		
Weight of can, W_c(g)	5.42		
Weight of water, W_w(g)	37.20		
Weight of dry soil, W_s(g)	110.27		
Moisture content, ω (%)	33.74		

2. PLASTICITY TESTS

General

Generally there are four states of consistency, i.e. degree of firmness, for clays and related fine grained soils: liquid, plastic, semisolid, and solid. The dividing line between liquid and plastic states is liquid limit, the dividing line between plastic and semisolid states is plastic limit, and the dividing line between semisolid and solid states is shrinkage limit. The liquid, plastic and shrinkage limits are therefore quantified in terms of water content. The difference between the liquid limit and plastic limit is the plastic index. It is the range with in which a material has a plastic consistency.

The three limits and the index are useful numbers in classifying soils and making judgments in regard to their applications. Hence, the appropriate laboratory procedures for determining the liquid limit and plastic limit of the western Ethiopia lateritic soils are given hereunder.

As explained, the liquid limit is the dividing line between liquid and plastic states, i.e. it is the moisture content of the material at the upper limit of the plastic range. The liquid limit is quantified for a given soil as a specific water content; from a physical stand point, it is the water content at which the shear strength of the soil becomes so small that the soil "flows" to close a standard grove cut in a sample of soil when it is jarred in a standard manner.

The liquid limit is identified in the laboratory as that water content at which the groove is closed ½ in. when the soil sample is jarred in the standard manner by exactly 25 drops (or blows) from a height of 1 cm in a standard liquid limit device.

Apparatus Required

- Liquid limit device (see Figure A-1)
- Grooving tool (see Figure A-2)
- Spatula
- Drop gage- a metal block for adjusting the height of drop of the cup (see Figure A-3)
- Balance (with accuracy to 0.01g)
- Mixing dishes

- No. 40 sieve
- Saucepans
- Oven (with accurate temperature control and temperature gage)
- Metal boxes/Containers (e.g., tin or aluminum moisture cans with lids)
- Rubber-covered pestle

Figure A- 1 Hand operated liquid-limit device

Dimensions

Letter	A△	B△	C△	D△	E△	F△
MM	2 ± 0.1	11 ± 0.2	40 ± 0.5	8 ± 0.1	50 ± 0.5	2 ± 0.1

Letter	G	H	J	K△	L△	N
MM	10 minimum	13	60	10 ± 0.05	60 deg ± 1 deg	20

△ Essential dimensions

= Back at least 15 mm from tip

Note: Dimension A should be 1.9-2.0 and dimension D should be 8.0-8.1 when new to allow for adequate service life

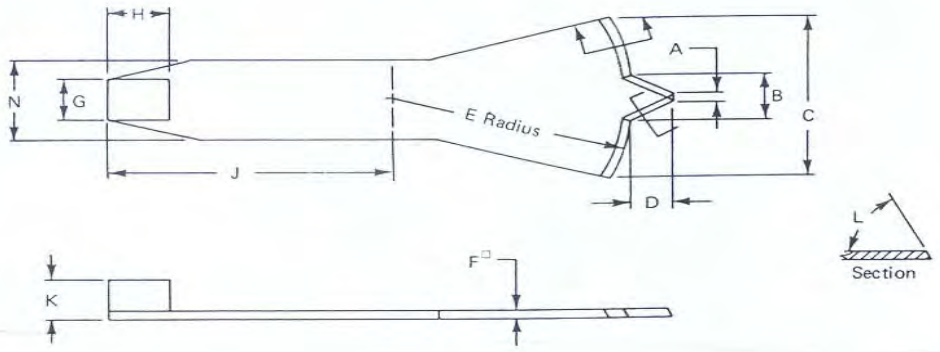


Figure A- 2 Grooving tool

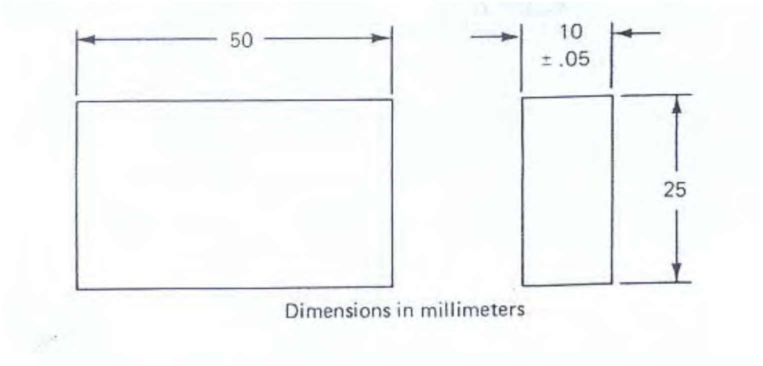
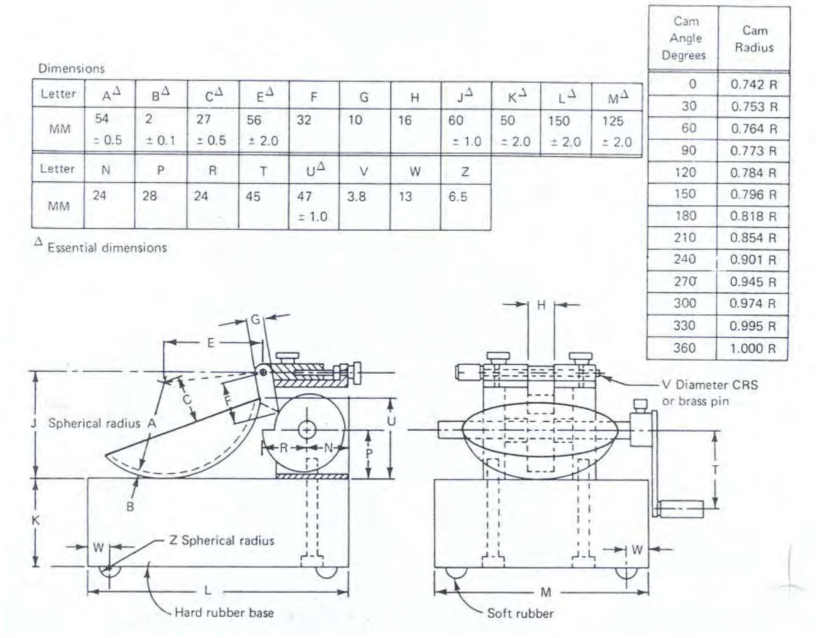


Figure A- 3 Height of drop gage

<u>Adjustment of liquid-limit device</u>

Before using the liquid-limit device, it must be adjusted so the cup in which the soil is placed falls exactly 1 centimeter. The handle of the grooving tool has a 1-centimeter gage which is used to measure this distance.

a) Remove cup from device and make a pencil cross of center of shiny spot caused by cup striking base.
b) Replace cup in device and turn crank until cup is raised to its highest elevation.
c) Insert gage and check distance from pencil marks to base in manner shown in Figure A-4. Loosen lock screw and turn adjusting screw until distance is exactly 1 centimeter. (see Note 2.1)



Dimensions

Letter	A$^{\Delta}$	B$^{\Delta}$	C$^{\Delta}$	E$^{\Delta}$	F	G	H	J$^{\Delta}$	K$^{\Delta}$	L$^{\Delta}$	M$^{\Delta}$
MM	54 ± 0.5	2 ± 0.1	27 ± 0.5	56 ± 2.0	32	10	16	60 ± 1.0	50 ± 2.0	150 ± 2.0	125 ± 2.0

Letter	N	P	R	T	U$^{\Delta}$	V	W	Z
MM	24	28	24	45	47 ± 1.0	3.8	13	6.5

$^{\Delta}$ Essential dimensions

Cam Angle Degrees	Cam Radius
0	0.742 R
30	0.753 R
60	0.764 R
90	0.773 R
120	0.784 R
150	0.796 R
180	0.818 R
210	0.854 R
240	0.901 R
270	0.945 R
300	0.974 R
330	0.995 R
360	1.000 R

Figure A- 4 Adjustment for height of drop

Preparation of Test Sample

Plasticity tests are made only on the soil fraction which passes the No.40 sieve. The separation on the No. 40 sieve is made either by dry sieving or by a slower wet sieving process. The actual field conditions should determine the preparation method. The results of the plasticity tests run both wet and dry preparation method will indicate the change due to dehydration.

I. Dry Method

a) Select sufficient soil sample to provide 150 to 200 grams of material passing the 425-µm (No. 40) sieve after processing.
b) Air-dry the sample by exposing to direct rays of sun/a draft/ or air-dry the sample inside the laboratory or in the shade (in the case of dry atmosphere), i.e. at room temperature, until the soil clods will pulverize readily (see Note 2.2 & Note 2.3).
c) Pulverize the sample/dry material/ with rubber-covered pestle or in some other way that does not cause disaggregation/breakdown of individual soil grains on clean, smooth surface (see Note 2.4 & Note 2.5).
d) Screen powdered/pulverized/ sample through the No.40 sieve and discard the material retained on sieve.
e) Mix soil passing No. 40 sieve with distilled/de-mineralized/ water until it has the consistence of a very thick, smooth paste. Then, cover with damp paper or cloth and let stand for not less than 1 hour.

II. Wet Method

a) Select a sufficient quantity of soil sample at natural moisture content to provide 150 to 200 grams of material passing the 425-µm (No. 40) sieve after processing.
b) Transfer sample to saucepan or dish and cover with sufficient water. Let soak until all material is disintegrated or softened and the fines no longer adhere to the surface of coarse particles, this may require 2 to 12 hours.
c) Place a No. 40 sieve in a clean saucepan or dish and transfer entire soaked sample into the sieve. Wash any material still adhering to the soaking pan into the sieve by squirting water from the battery filler.

d) Pour clean water into pan containing sieve until level of water is about ½-inch above mesh in sieve.

e) Without lifting sieve, agitate it with one hand. At the same time, stir material with the other hand until all fine material appears to have passed through sieve.

f) Hold sieve slightly above water surface in pan and squirt water from battery filler onto sieve until retained particles and the sieve are clean. Discard material retained in sieve.

g) Place pan where it will not be disturbed and block it up on one side so water on the other side barely riches rim of pan. Allow soil to settle for several hours *(*see Note 2.6).

h) Pour off liquid slowly by gradually increasing tilt of pan until cloudy layer overlaying the sediment reaches rim of pan.

f) Air-dry material to the consistency of a thick, smooth paste having a consistency within the 10 to 20 blow range and put in small mixing dish.

Note 2.1: The 1.0 cm gage must be placed to measure the distance from the shiny spot to the base and not the distance from the lowest point of the cup. Cylindrical gages with beveled edges cannot be used. Use a flashlight or other strong light behind gage when checking distance

Note 2.2: To air-dry the material, place it in pans or spread it on a canvas and expose it to direct rays of sun or to a draft (frequent agitation or stirring speeds up the drying process). In case of dry atmosphere, the material also dries readily inside the laboratory or in the shade. A fan blowing air over the sample greatly increases the rate of evaporation/drying.

Note 2.3: In areas of high rainfall it may be difficult to dry soils during construction; hence, the plasticity tests should be run from the natural moisture content, and not allowed to dry in the laboratory. However, if the construction is during the dry season or in an area of low rainfall, then the soils should be air-dried in the laboratory. In all cases, the laboratory pretreatments should reflect actual field conditions. Hence, lateritic soil samples should not be over-dried prior to testing since the soils will not experience such high temperatures in the field.

Note 2.4: Lateritic soils are susceptible to breakdown with manipulation; hence test procedures should be more rigidly controlled. Excessive manipulation during testing and sample preparation leads to crumbling of the soil structure and disaggregating of soil particles; these effects produce fines which will result in higher liquid limit values. Hence, In order to control this problem the mixing times shall be kept to a minimum, generally about 5 minutes, and use fresh soil for each moisture content point in the plasticity tests. In addition to these, the soils shall be broken-down by soaking in water or in such a way that breakdown/disaggregation of soil grains is omitted during preparation of test sample.

Note 2.5: When the coarse particles found during pulverization are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-µm (No. 40) sieve, but remove by hand or by washing.

Note 2.6: For most lateritic soils, material in suspension will settle out. If there is no indication of this after several hours, place filter paper in a funnel and place wet soil inside the funnel. Place the funnel in a jar or other container and allow to stand until all the excess water is filtered off.

2.1 LIQUID LIMIT (LL) TESTS

Just before making liquid-limit test, thoroughly mix the prepared sample once more with spatula and set aside about 1 heaped teaspoonful of material for the plastic-limit test.

Test Procedures

1) ***Dryly prepared samples (Samples prepared using Dry method)***

a) Transfer enough material from mixing dish into brass cup of liquid-limit device to fill the cup about one-third full.

b) Hold cup and use spatula to mix and spread material, forming a smooth cake about ½-inch deep in lower half of cup.

c) Hold grooving tool with rounded edges downward, index finger against flat face.

d) Place point of tool on upper edge of soil cake with tool perpendicular to surface of cup.

e) Draw tool down through the center of cake along a line extending from the center of the cup handle. At the same time, tilt the tool so it remains perpendicular to the bottom surface *(*see Note 2.8).

f) Clean grooving tool by wiping thumb over cutting edge before laying it aside. If soil dries on tool, time is lost in cleaning it later.

g) With striking parts of the liquid-limit device clean and dry and height of drop properly adjusted, place cup in device, turn crank at rate of about two blows per second, and count number of blows required to close bottom of groove for a distance of about ½-inch *(*see Note 2.9).

h) Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including the portion of the groove in which the soil flowed together. Then place soil in small weighted metal box and cover tightly.

i) Remove cup from device, remix to mixing dish and add a slight amount of water to increase the water content of the soil and decrease the number of blows required to close the groove. And, repeat steps (a) through (h) for at least two additional trials producing successively lower number of blows to close the groove. One of the trials shall be for a closure requiring 25 to 35 blows, one trial for a closure between 20 to 30 blows, and one trial for a closure requiring 15 to 25 blows.

j) Determine moisture content of all samples obtained during test according to the moisture content test shown above. (Cans must be properly numbered and recorded).

2) ***<u>Wetly prepared samples (Samples prepared using wet method)</u>***

a) Transfer enough material from mixing dish, wetly prepared test sample, into brass cup of liquid-limit device to fill the cup about one-third full *(*see Note 2.7).

b) Hold cup and use spatula to mix and spread material, forming a smooth cake about ½-inch deep in lower half of cup.

c) Hold grooving tool with rounded edges downward, index finger against flat face.

d) Place point of tool on upper edge of soil cake with tool perpendicular to surface of cup.

e) Draw tool down through the center of cake along a line extending from the center of the cup handle. At the same time, tilt the tool so it remains perpendicular to the bottom surface *(*see Note 2.8).

f) Clean grooving tool by wiping thumb over cutting edge before laying it aside. If soil dries on tool, time is lost in cleaning it later.

g) With striking parts of the liquid-limit device clean and dry and height of drop properly adjusted, place cup in device, turn crank at rate of about two blows per second, and count number of blows required to close bottom of groove for a distance of about ½-inch *(*see Note 2.10).

h) Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including the portion of the groove in which the soil flowed together. Then place soil in small weighted metal box and cover tightly.

i) Remove cup from device, remix to mixing dish and air-dry the sample slowly to decrease the water content of the soil and increase the number of blows required to close the groove. This is to perform the blow count determination for different moisture contents as the soil slowly dries out. And, repeat steps (a) through (h) for at least two additional trials producing successively higher number of blows to close the groove. One of the trials shall be for a closure requiring 15 to 25 blows, one trial for a closure between 20 to 30 blows, and one trial for a closure requiring 25 to 35 blows.

j) Determine moisture content of all samples obtained during test according to the moisture content test shown above. (Cans must be properly numbered and recorded).

Note 2.7: For the case of wet samples, i.e. for the test samples which were prepared according to *wet method* shown above in the "Preparation of Test Sample". Initially the samples should be air-dried to the consistency of a thick, smooth/uniform paste having a consistency within the 15 to 25 blows range.

Note 2.8: For clays containing little or no sand, cut groove with one smooth continuous stroke. However, for very sandy clays, silts having little plasticity, and some organic soils, the tool cannot be drawn through sample without tearing sides of groove. For these soils, cut groove with a spatula and check dimensions with tool.

Note 2.9: If groove is not closed ½-inch in 25 to 35 blows initially, i.e. for the first point, add water and remix or dry sample to a consistency with in this range.

Note 2.10: If groove is not closed ½-inch in 15 to 25 blows initially, i.e. for the first point, add water and remix or dry sample to a consistency with in this range.

Data collection

As indicated previously, the liquid-limit is that the water content of the soil at which the standard groove is closed a distance ½ in. by exactly 25 drops. This is determined by plotting, on semi logarithmic graph paper, water content along the ordinate (arithmetical scale) versus number of drops along the abscissa (logarithmic scale) and drawing the best straight line through the plotted points. The resulting graph is referred to as a flow curve. From the flow curve, the liquid limit can be read as the water content at 25 drops.

From the preceding, the data to be collected for each trial are *the number of drops (N) required to close the groove and the water content (ω) of the soil at that number of drops.* Recalling section A that, in order to determine water content, the weight of the container (w_c), weight of container plus wet soil (w_1), and weight of container plus oven-dried soil (w_2) must be obtained. Since more than one water contents must be determined, each container should be properly labeled or numbered and recorded. Generally the following data should be collected for each trial in this test:

- Number of drops (N)
- Container identification number
- Weight of container, w_c
- Weight of container plus moist soil, w_1
- Weight of container plus oven-dried soil, w_2

2.2 PLASTIC LIMIT (PL) AND PLASTICITY INDEX (PI) TESTS

The small sample which was set aside at the start of the liquid-limit test is allowed to dry to a consistency such that the material will not stick to the hands, yet can still be rolled into a thread without crumbling

Test Procedure

a) Take not more than one-half of this sample and roll with palm of hand on any clean, smooth surface such as a sheet of paper, to form a 1/8-inch threat about 3 inches long.
b) Fold thread and press together into a lump and then roll it out again.
c) Repeat step (b), gradually reducing moisture content by evaporation as the sample is handled causing threads to become stiffer.
d) The plastic limit (PL) is reached when the thread crumbles into a number of pieces while begin rolled (see Note 2.11).
e) Immediately place the crumbled thread into a small metal box and determine moisture content.
k) Make another PL determination for a check, using material from remaining portion of original sample.

Note B.11: If any doubt exists as to whether the PL has been reached, lump the pieces together and roll out again.

Data sheet

The same data sheet is used for both the plastic-limit and liquid-limit tests as given blow, i.e. Table A - 3.

Plasticity Index

The numerical difference between the liquid limit (LL) and the plastic limit (PL) is the plasticity index (PI).

PI = LL -PL -- (A-2)

Sample Calculations

Table A- 3 Plasticity test data sheet

DATA SHEET
PLASTICITY TEST

Sample name: TS1-2
Depth: 2.0m
Description of sample: Yellowish color silty gravel
Tested by: W.M.

Project area: NJB
Location(station): 10+880, 1.0km RHS (Test Pit)
Date: 1/12/2008

Type of test	**Liquid Limit**				**Plastic Limit**	
Determination No.:	**1**	**2**	**3**	**4**	**1**	**2**
Number of drops	34	27	21	16		
Container(can) no.	33	D26	35	C34	D23	108
Weight of can + moist soil, W_1(g)	40.29	41.92	36.70	29.57	24.56	23.57
Weight of can + dry soil, W_2(g)	34.17	35.11	31.43	23.98	23.93	23.20
Weight of can, W_c(g)	22.03	22.18	21.72	14.11	21.96	22.00
Weight of water, W_w(g)	6.12	6.81	5.27	5.59	0.63	0.37
Weight of dry soil, W_s(g)	12.14	12.93	9.71	9.87	1.97	1.20
Moisture content, w(%)	50.41	52.67	54.27	56.64	31.98	30.83

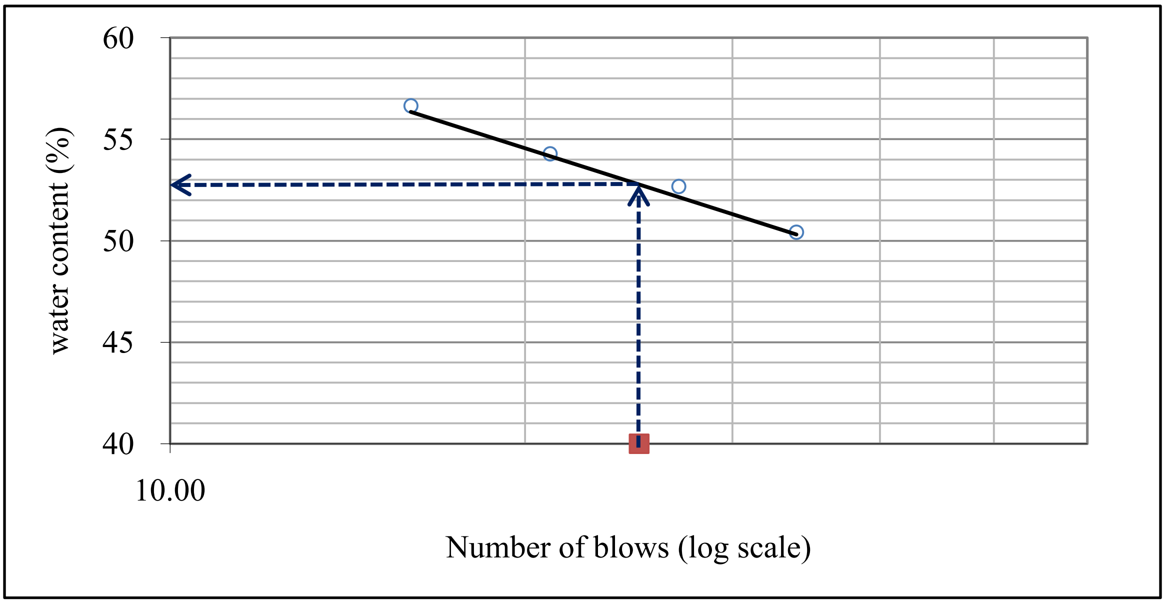


Figure A- 5 *Flow curve*

Table A- 4 Summary of test results

Liquid Limit (LL), from the flow curve =	53.35	%
Plastic Limit (PL) =	31.41	%
Plasticity Index (PI) =	21.94	%

3. GRAIN SIZE ANALYSIS TESTS

General

The determination of grain-size distribution in a soil, called grain-size analysis, is made by a screening process (sieve analysis) for coarse grained soils (for particle sizes larger than 75 -µm), and by a settling/sedimentation process in water (i.e. wet mechanical analysis), using a hydrometer, for fine-grained soils (for particle sizes smaller than 75-µm). When both processes are used on the same sample, the test is called combined grain-size analysis.

Because of the tendency of some lateritic soils to form aggregations while drying at higher temperatures, a sieve analysis should be made on the sample after the fines are removed by washing. In addition to this, relatively weak coarse particles may also cause problems in grading analysis as they become finer during sample preparation i.e. during pulverization. Hence, it is important that the sample preparation and testing procedures should not fracture the coarse particles.

Apparatus Required

- Balance (with accuracy to 0.01g for weighing the material passing No. 10 sieve and a balance sensitive to 0.1% of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve)
- Stirring apparatus
- Hydrometer (an ASTM hydrometer conforming to the requirements for hydrometers 151H or 152H in specification E 100)
- Sedimentation cylinder (a glass cylinder essentially 18 in. (457 mm) in height and 2 ½ in. (63.5 mm) in diameter and marked for a volume of 1000-mL)
- Thermometer (with accuracy to 1^{o}F (0.5^{o}C))
- Water bath or constant-temperature room (for maintaining the soil suspension at a constant temperature during the hydrometer analysis)
- Beaker (a capacity of 250-mL)
- Timing device (a watch or clock with a second hand)
- Saucepans
- Set of sieves

- Oven (with accurate temperature control and temperature gage)
- Set of portable screens
- Paint brush

Preparation of Test Sample

a) Two samples shall be selected by the method of quartering or by use of a sample splitter (one for the gradation test and the other for moisture content).

b) The gradation sample shall weigh, in its natural moisture conditions, not less than the amount indicated in the following table.

Table A- 5 Minimum Weight of gradation sample (Lyon Associates, 1971)

Nominal Maximum sieve size	Approximate Minimum Weight of Sample, kg
No. 4 (4.75-mm)	1.0
½-in. (14.25-mm)	2.0
¾-in. (19.0-mm)	3.0
1-in. (25.0-mm)	4.0
1½-in. (37.5-mm) or over	5.0

c) The moisture sample shall weigh at least 30 per cent of the gradation sample.

d) Weigh the graduation sample in its wet condition and place in a container. Add sufficient water to the sample in the container to cover it.

e) Prepare a nest of two sieves with a No. 200 (0.075-mm) sieve on the bottom and a No. 10 (2.0-mm) sieve on the top.

f) Transfer the sample to the nested sieves and wash with running water. When the sample is larger than can be handled at one time on the nested sieves, wash a portion of the sample and transfer it to a container in which it is to be dried (see Note 3.1).

g) Dry and combine the washed materials retained on the nested No. 10 & No. 200 sieves to a constant weight at a temperature not to exceed 230°F or 110°C (see Note 3.2).

Note 3.1: Tapping of the sieves expedites the washing procedure.

Note 3.2: The dry weight to be used in the computation for the gradation shall be computed using the initial wet weight and the moisture content of the sample, i.e. the dry-weight is equal to wet-weight divided by (1 + moisture content).

Test Procedures

- ***Sieve Analysis of portion retained on No. 10 & No. 200 sieves***

a) Transfer dry sample to set of sieves (coarse sieves at top, fine sieves at bottom) with the sieve pan on bottom. Place cover on top and shake the stack vigorously with a horizontal rotating motion. The sieves may be jarred occasionally by dropping lightly on several thicknesses of magazines. Do not drop directly on work bench or table, this will damage sieves. The shaking period depends on the amount of fine material in the sample, but should not be less than 15 minutes for most fine-grained soils (see Note 3.3).

b) Transfer material from largest screen to pan of balance and weight to nearest 5 grams. Record size of largest particle. Place material in separate container and save until test is completed. For sample weighting less than 50 grams, weigh each fraction on a balance to nearest gram.

c) Repeat procedure for each successively smaller screen size. Individual stone particles caught in the wire screens should not be forced through screens but should be removed by hand and included with fraction before weighing. The finer sieves should be inverted over the scale pan and brushed clean.

Note 3.3: Large samples containing many coarse stones should first be screened through the portable screen set. The number and size of screens and sieves to be used depends on the type of soil tested and the purpose of the test. It is often permissible to omit a few of the intermediate sizes, as illustrated in the sample data sheet.

Sample calculation

Table A- 6 Sieve analysis data sheet

DATA SHEET
SIEVE ANALYSIS

Moisture Content =	35.13 %		Project Area:	NJB road
Wt. of wet sample =	3,562.50	gm	Sample Name:	TS1-1
Wt. of original dry sample =	2,636.35	gm	Location(station):	10+880, 1.5 km RHS
Wt. after washing & OD =	1,970.61	gm		Test Pit
Washing loss =	665.74	gm	Date Tested:	7/11/2008

SIEVE OR SCREEN	SIEVE OPENING (mm)	WT. RETAINED ON SIEVE (gm)	WT. PASSING SIEVE	
			(gm)	(%)
3"	75	0.00	2,636.35	100.00%
2"	50.8	0.00	2,636.35	100.00%
11/2"	38.1	0.00	2,636.35	100.00%
1"	25.4	0.00	2,636.35	100.00%
3/4"	19.1	135.15	2,501.20	94.87%
3/8"	9.5	369.29	2,131.91	80.87%
No. 4	4.75	506.16	1,625.75	61.67%
No. 10	2.00	359.86	1,265.89	48.02%
No. 40	0.425	176.00	1,089.89	41.34%
No. 100	0.150	319.01	770.88	29.24%
No. 200	0.075	102.14	668.74	25.37%
Retained in pan - - - - - - - - - - - Washing loss - - - - - - - - - - - - - Pan total - - - - - - - - - - - - - - - -		3.00 665.74 668.74		
TOTAL		2,636.35		

Remarks:

Error = 7.72 gm (add to wt. of materials retained in largest fraction, for this case it is in No. 4 sieve)

Error = (7.72/2,636.35)x100% = 0.29% < 3%

a) Obtain sum of weights retained on each sieve and check this total or (sum) against the weight of original dry sample (see Note 3.2 that the dry weight is computed using wet weight and moisture content of the test sample). If error exceeds about 3%, reweigh each fraction or repeat test.

b) If error is less than 3 %, apply numerical value of error to weight of largest fraction.

c) Compute the weight of material passing each sieve. For example:

Wt passing No.4 sieve = (wt of original dry sample) - (wt of material retained on No. 4 and all larger sieves)

= 2,636.35 - (135.15 + 369.29 + 506.16)

= 2,636.35 – 1,010.6 = 1,625.75 gm

d) Compute the percentage by weight of material passing each sieve. For example:

$$\% \text{ passing No.4 sieve} = 100 \times \frac{wt\ passing\ No.\ 4\ sieve}{wt\ of\ original\ dry\ sample}$$

$$= 100 \times \frac{1{,}625.75}{2{,}636.35} = 61.67\ \%$$

- ***Hydrometer Analysis of portion passing the No. 10***

The physical characteristics of a fine-grained soil are generally identified with greater accuracy by the plasticity test than by the grain-size distribution. However, a wet mechanical analysis/hydrometer analysis/ is required to determine the percentage of material smaller than 0.075mm in diameter. Laboratory testing procedure required for the analysis of grain sizes less than 0.075s mm in diameter (passing No.200 sieve) is not included in the set. This test can be done using the step-by-step test procedures described in ASTM D 422-63.

Grain-size Distribution Curve

Normally, the results of each grain-size analysis of soils are reported in the form of grain-size distribution curve (Figure A-6). As an alternative, the analysis may be reported in tabular form, giving percentage passing of various sieve sizes or percentages found within various particle-size ranges.

Generally, grain-size analysis is widely used in the identification and classification of soils. It is also utilized in part of the specification of soils for airfields, roads, earth dams, and other soil embankment construction.

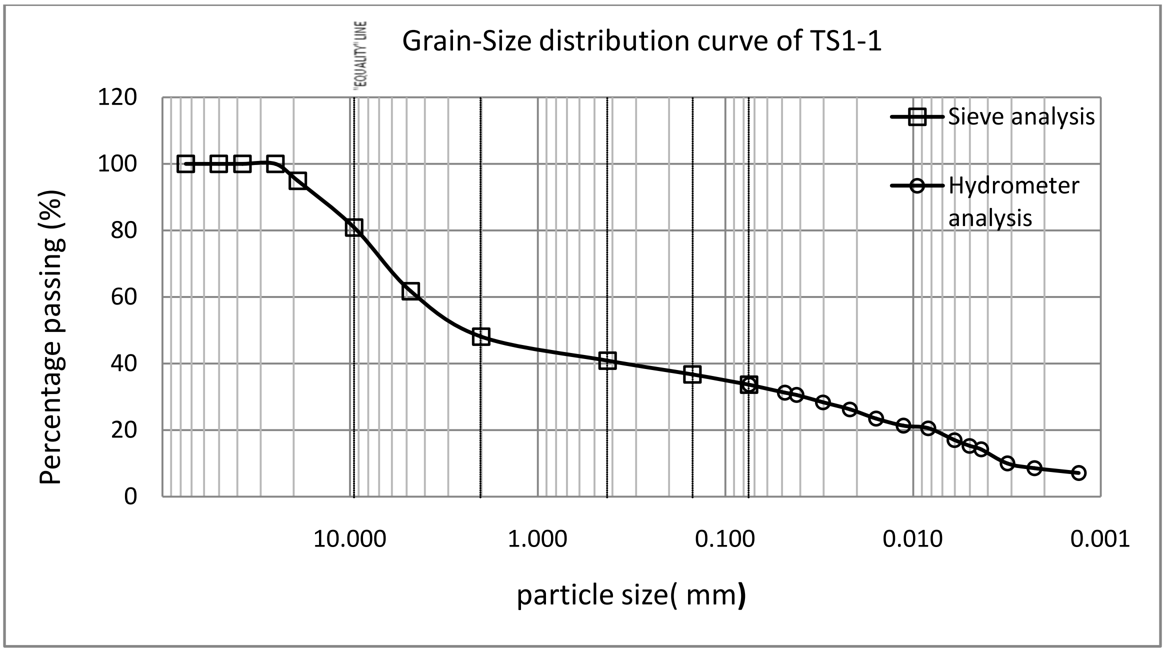


Figure A - 6 Grain-Size distribution curve

4. SPECIFIC GRAVITY TEST

4.1 INDIVIDUAL STONES

General

In general, the term specific gravity of soil is defined as the ratio of the weight of solid matter of a given soil sample to the weight of an equal volume (i.e., equal to the volume of solid matter) of water. In this method the determination of the specific gravity of individual stones, weighing less than 200 gm, is given by weighing on the triple-beam balance. Usually the specific gravity of stones with their natural moisture content is required (ASTM Method C 127 can be consulted as an alternative method).

Apparatus Required

- Triple-beam balance
- Light cord or thread
- Small can to hold water

Preparation of Test Sample

For the determination of the specific gravity of stones, select representative sample (stones) which are at their natural moisture content condition.

Test Procedures

a) Loop a small thread around stone and hang from lower hook on triple beam balance. Weigh to nearest 0.1 gram.
b) Place small can of water on platform, immerse object in water, and reweigh to nearest 0.1 gram.
c) Calculate specific gravity of stone as shown in sample calculation. If cord or thread is very light, its weight can be neglected.

Sample calculation

Wt of stone in air ------------------------------------155.6 gm

Wt of stone in water --------------------------------110.50 gm

$$\text{Specific gravity} = \frac{\text{Wt of stone in air}}{\text{Wt of stone in air} - \text{Wt of stone in water}}$$

$$= \frac{155.60}{155.60 - 110.50} = 3.45$$

4.2 SOIL SAMPLES

General

As defined previously, the term specific gravity of soil is defined as the ratio of the weight of solid matter of a given soil sample to the weight of an equal volume (i.e., equal to the volume of solid matter) of water. The specific gravity, Gs, of a soil is used to calculate parameters such as clay fraction, void ratio and porosity. In residual soils found in western Ethiopia the specific gravity of the test samples are higher if the samples are kept at their moist condition until specific gravity test is conducted.

The specific gravity of lateritic soils may be unusually high or unusually low as discussed by different authors. It is thus essential that the specific gravity be determined in the laboratory using an accepted standard test procedure. The soil has to be in its natural moisture content and pre-test drying of the sample should be avoided as it tends to reduce the measured specific gravity compared with the soils at their natural moisture content. The dry mass of the lateritic soils should be calculated by drying the soil specimen after the specific gravity test has been completed and using a lower oven temperature, say 50^{o}C, rather than using 105^{o}C oven temperature (see Note 4.1). This method covers the determination of specific gravity of soil (i.e., the specific gravity of the solid matter of the soil) using pycnometer.

Apparatus Required

- Pycnometer (volumetric flask), preferably with a volume of 500mL
- Balance (with accuracy to 0.01 gm)

- Thermometer
- Drying oven
- Vacuum pump
- Evaporating dish
- Spatula
- Mechanically operated stirring device (malt mixer)
- Large beaker

Calibration of Pycnometer

One parameter that is required in order to compute the specific gravity of soil is the weight of the pycnometer when filled with water, W_{pw}. The value of W_{pw} is not constant; it varies slightly as a function of water temperature (for the same volume of water). Furthermore, W_{pw} must be known at a temperature that equals the temperature of the same pycnometer when filled later with a mixture of water and soil sample. The value of W_{pw} at any desired temperature can be obtained by proper calibration of the pycnometer. The following procedure may be used to calibrate the device:

(1). The pycnometer must be cleaned, dried, and then weighed, and the weight of the pycnometer, W_p, recorded.

(2). The pycnometer is then filled with distilled water that is approximately at room temperature, and the weight of the pycnometer plus water, W_{pw}, is accurately determined and recorded.

(3). The water temperature T_i must be determined (and recorded) by inserting a thermometer in the water.

(4). The value of W_{pw} can then be computed for any other water temperature T_x, from equation (A-3). The required densities of water may be obtained from Table A-7. (see Note 4.2)

$$W_{pw}(\text{at } T_x) = \frac{\text{density of water at } T_x}{\text{density of water at } T_i}\left[W_{pw}(\text{at } T_i) - W_p\right] + W_p \text{ -------------- (A-3)}$$

Table A- 7 Relative Densities of Water and Conversion Factor K for Various Temperatures (ASTM, 2004)

Temperature (°C)	Relative Density of Water	Conversion Factor K [see Eq. (A-3)]
18	0.9986244	1.0004
19	0.9984347	1.0002
20	0.9982343	1.0000
21	0.9980233	0.9998
22	0.9978019	0.9996
23	0.9975702	0.9993
24	0.9973286	0.9991
25	0.9970770	0.9989
26	0.9968156	0.9986
27	0.9965451	0.9983
28	0.9962652	0.9980
29	0.9959761	0.9977
30	0.9956780	0.9974

Preparation of Test Sample

Soil to be used in a specific gravity test shall contain its natural moisture content, or shall be in moist condition. The weight of the test sample (on an air-dried basis) should be at least 25 gm. The weight of the soil (W_s) (again on an air-dried basis) should be determined at the end of the test by evaporating the water in an oven at a temperature of 50^{o}C (not exceeding 60 ^{o}C) which is equivalent to air drying temperature. The test samples which contain natural moisture content should be dispersed in the mechanically operated stirring device (malt mixer), before placing the mixture in the flask (i.e., pycnometer). During the determination of the dry mass the test samples shall be dried until successive sample weightings (greater than ½ hr.) show that no further weight loss is taking place or insignificant change (less than about 0.1%) (see Note 4.1).

Test Procedures

a) Place the moist test sample (at least 25 g when air-died later) in the pycnometer. Add distilled water to fill the volumetric flask about three-fourths full.

b) Remove entrapped air by either of the following methods: (1) subject the contents to a partial vacuum (air pressure not exceeding 100 mmHg) or (2) boil gently at least 10 minutes (min) while occasionally rolling the pycnometer to assist in the removal of the air. Subject the contents to reduce the pressure either by connecting the pycnometer directly to an aspirator or vacuum pump, or by use of a bell jar. Cool samples that are heated to room temperature.

c) Fill the pycnometer with distilled water, clean the outside, and dry with a clean, dry cloth. Determine the weight of the pycnometer and contents, i.e. the weight of pycnometer filled with water and soil, (W_{pws}) and the temperature in degree Celsius (T_x) of the contents (soil-and-water mixture).

d) Determine the weight of solids, W_s, by pouring soil-and-water mixture onto evaporating dish and then air-dried in an oven using a temperature not exceeding 50°C.

e) With the temperature of the soil-water mixture known (i.e., T_x known), the weight of the pycnometer when filled with water (at T_x temperature), W_{pw} (at T_x), can be computed from the calibration of the pycnometer using Eq. (A-3).

f) With these data now known, compute the specific gravity of soil by dividing the weight of the solids, W_s, by the weight of an equal volume of water, i.e. $W_s + W_{pw} - W_{pws}$.

g) In order to report the specific gravity based on water at 20°C, which is the usual practice, multiply the computed value in (f) by the conversion factor K which can be determined from Table A-7.

Data collection

Data collected in this test should include the following:

[A] Calibration of Pycnometer

- Weight of pycnometer, W_p (g)
- Weight of pycnometer plus water, W_{pw} (g)
- Observed temperature of water, T_i (ºC)

[B] Specific Gravity Determination

- Weight of pycnometer plus water and soil,(W_{pws}) (g)
- Temperature of content of pycnometer when W pws was determined, T_x (ºC)
- Weight of large evaporating dish or beaker, W_d (g)
- Weight of large evaporating dish or beaker plus oven-dried soil, W_{ds} (g)

Sample calculation

Table A- 8 Specific gravity determination data sheet

DATA SHEET
SPECITIC GRAVITY DETERMINATION

Sample Name:	TS1-1	Project area:	NJB
Depth:	0.6m	Location(station):	10+880, 1.5 km RHS
Description of sample:	Reddish brown color		(Test Pit)
Tested by:	W.M.	Date:	26-Jul-08

[A] Calibration of Pycnometer	**P3**	**P20**	**P41**
(1) Weight of dry, clean pycnometer, W_p (g)	45.88	45.38	49.92
(2) Weight of pycnometer + Water, W_{pw} (g)	145.44	145.04	149.60
(3) Observed temperature of water, T_i (^oC)	21	21	22
i. Relative density of water at T_x=	0.9982343	0.9982343	0.9982343
ii. Relative density of water at T_i=	0.9980233	0.9980233	0.9978019

[B] Specific Gravity Determination

Determination No.:	*1*	*2*	*3*
Weight of pycnometer + soil + Water, W_{pws} (g)	162.49	162.17	166.31
Temperature, T_x (^oC)	20	20	20
Weight of pycnometer + Water at T_x, W_{pw} (at T_x) (g)	145.46	145.06	149.64
Evaporating dish no.	1	2	3
Weight of evaporating dish,W_d (g)	5.6	7.0	6.1
Weight of evaporating dish + oven-dried soil, W_{ds} (g)	31.0	32.0	31.00
Wight of solids,W_s (g)	25.4	25.0	24.90
Conversion factor, K	1.0000	1.0000	1.0000
Specific gravitiy of soils, $G_s = \frac{KW_s}{W_s + W_{pw}(atT_x) + W_{pws}}$	3.03	3.17	3.02

Note 4.1: As samples containing natural moisture should be used for the test, the weight of the soil, W s, on an air-dried basis should be determined at the end of the test by emptying the contents of the pycnometer (i.e., the soil and water mixture) into a pre-weighed large evaporating dish or beaker (W_d) and oven-drying. Care must be taken not to lose any soil. If the weight of the evaporating dish (or beaker) plus the oven-dried soil, W_{ds}, is then determined, the weight of the air-dried soil can be computed ($W_s = W_{ds} - W_d$).

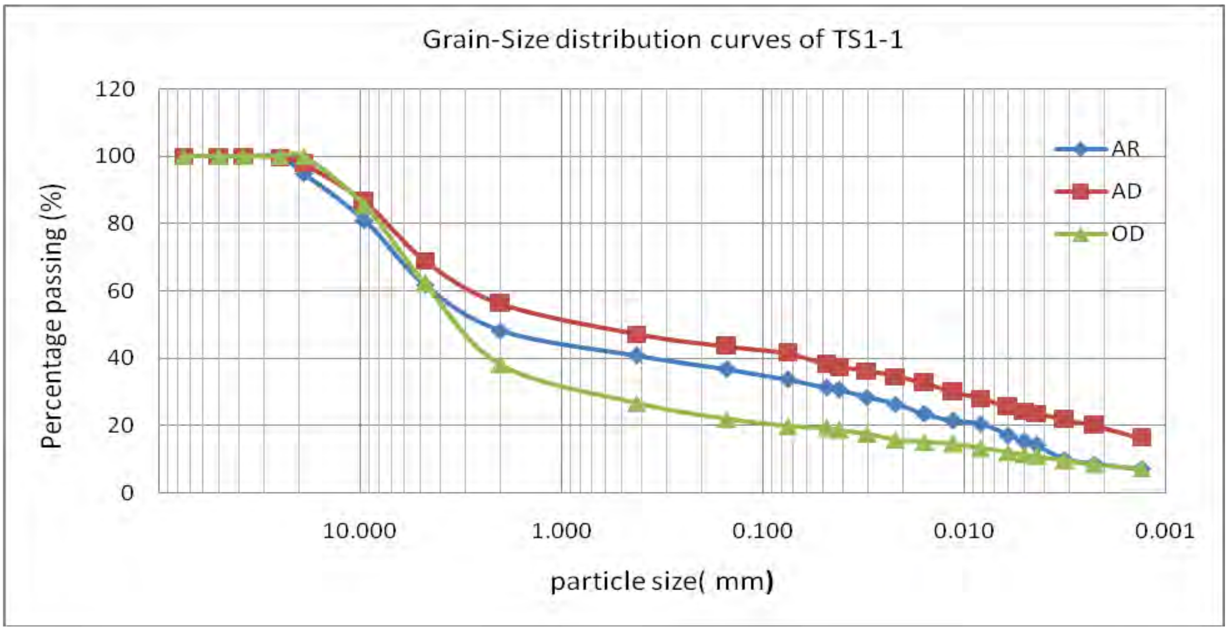
Note 4.2: If many determinations specific gravity are to be made using a particular pycnometer, it would be helpful to prepare a table (or graph) from which values of W_{pw} could be read for any desired water temperature. Such tables (or graphs) can be developed by using Eq. (A-3) to determine values of W_{pw} corresponding to a sufficient number of different temperatures T_x.

APPENDIX – B

GRAIN-SIZE DISTRIBUTION CURVES

Contents

1. GRAIN-SIZE DISTRIBUTION CURVES FOR VARIATION IN SAMPLE PRETREATMENTS /TESTING PROCEDURES/



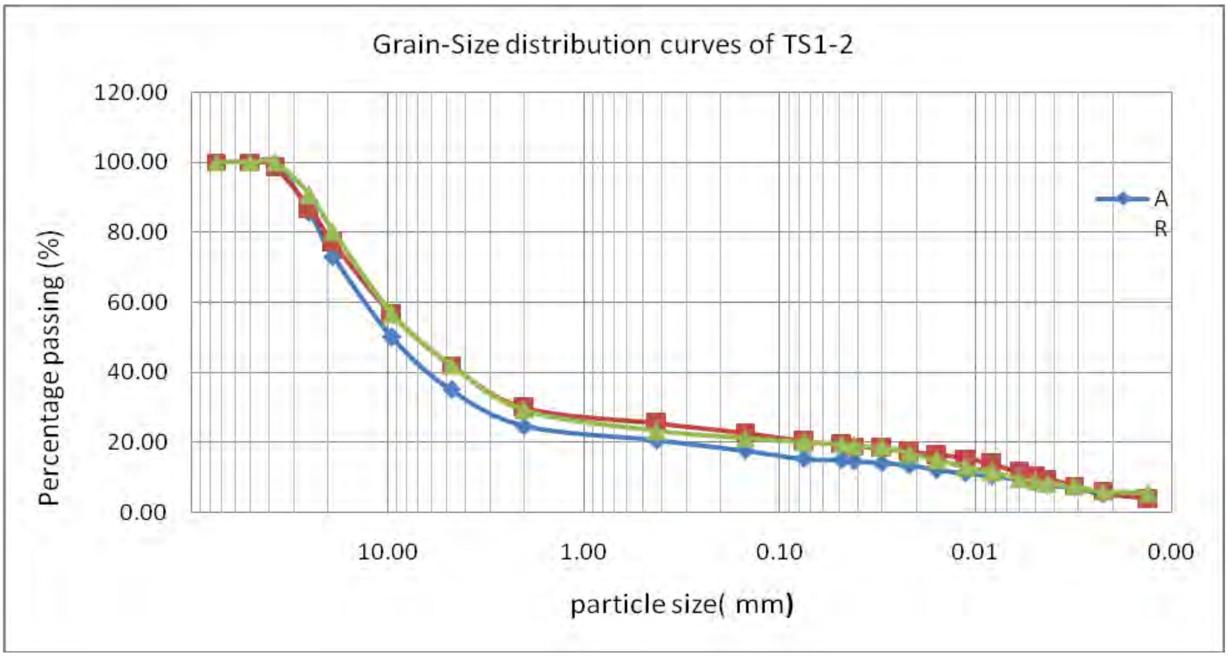
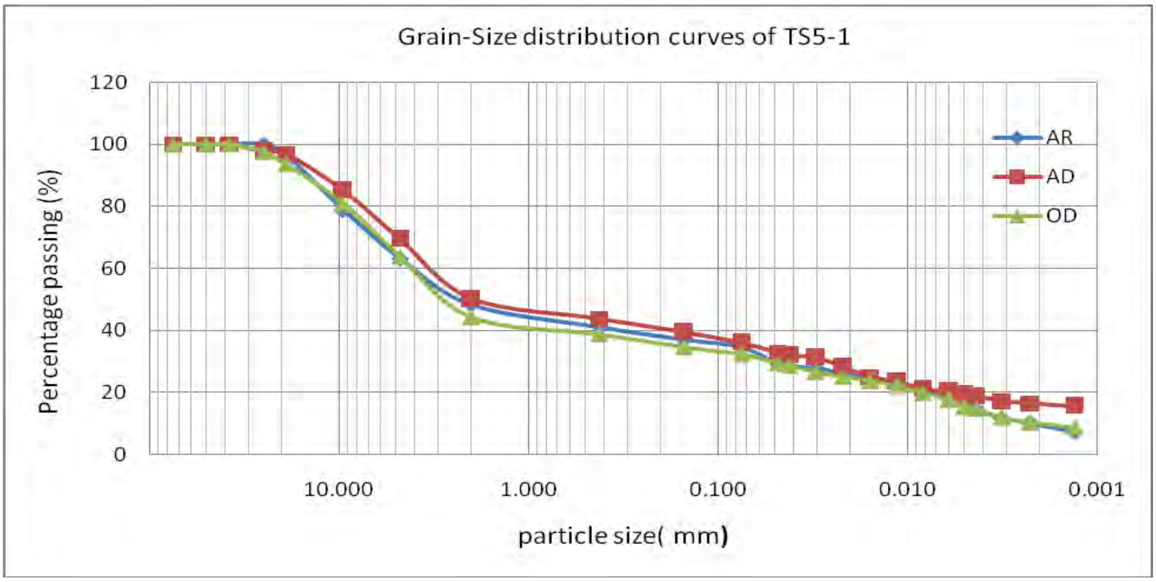
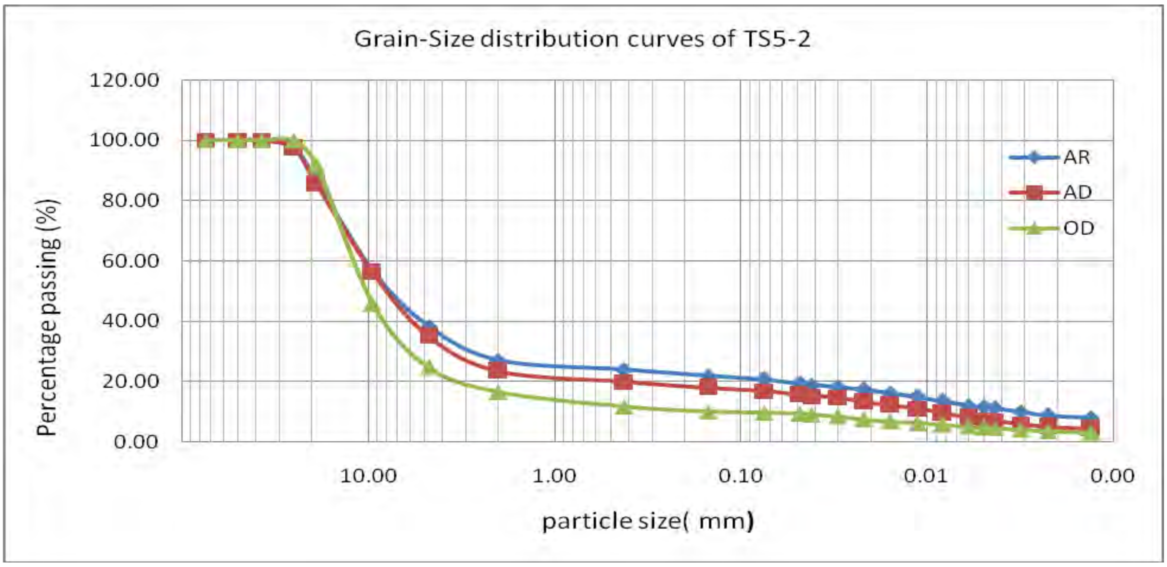


Figure B - 1 Grain-Size distribution curves of test samples TS1-1 & TS1-2





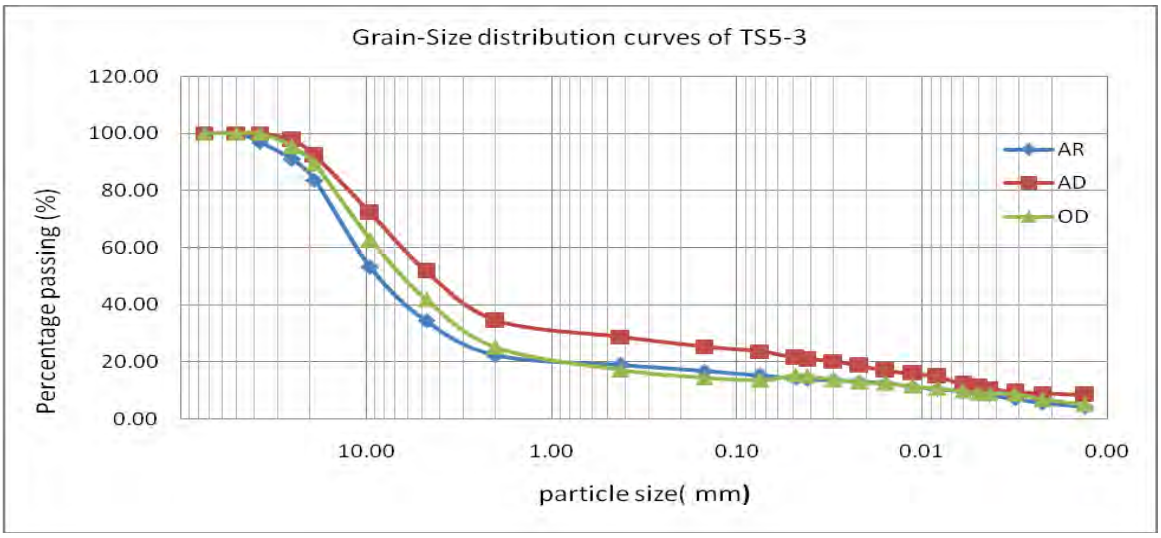
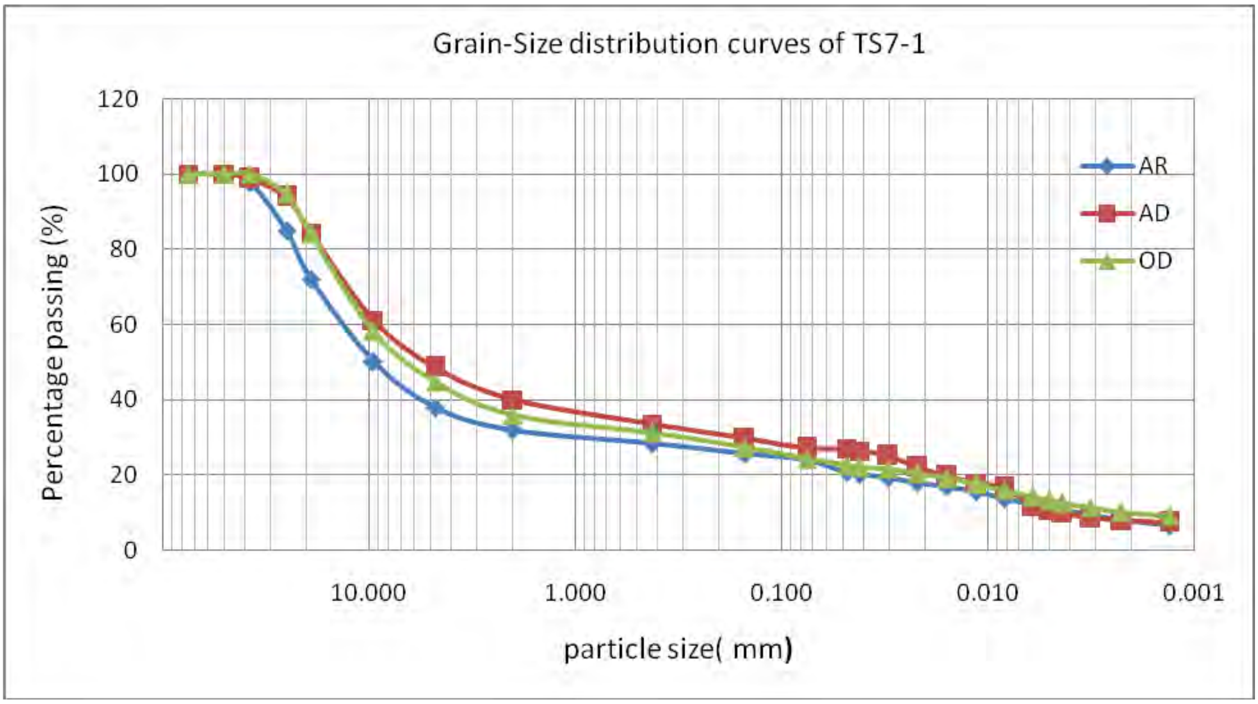


Figure B - 2 Grain-Size distribution curves of test samples TS5-1, TS5-2 & TS5-3



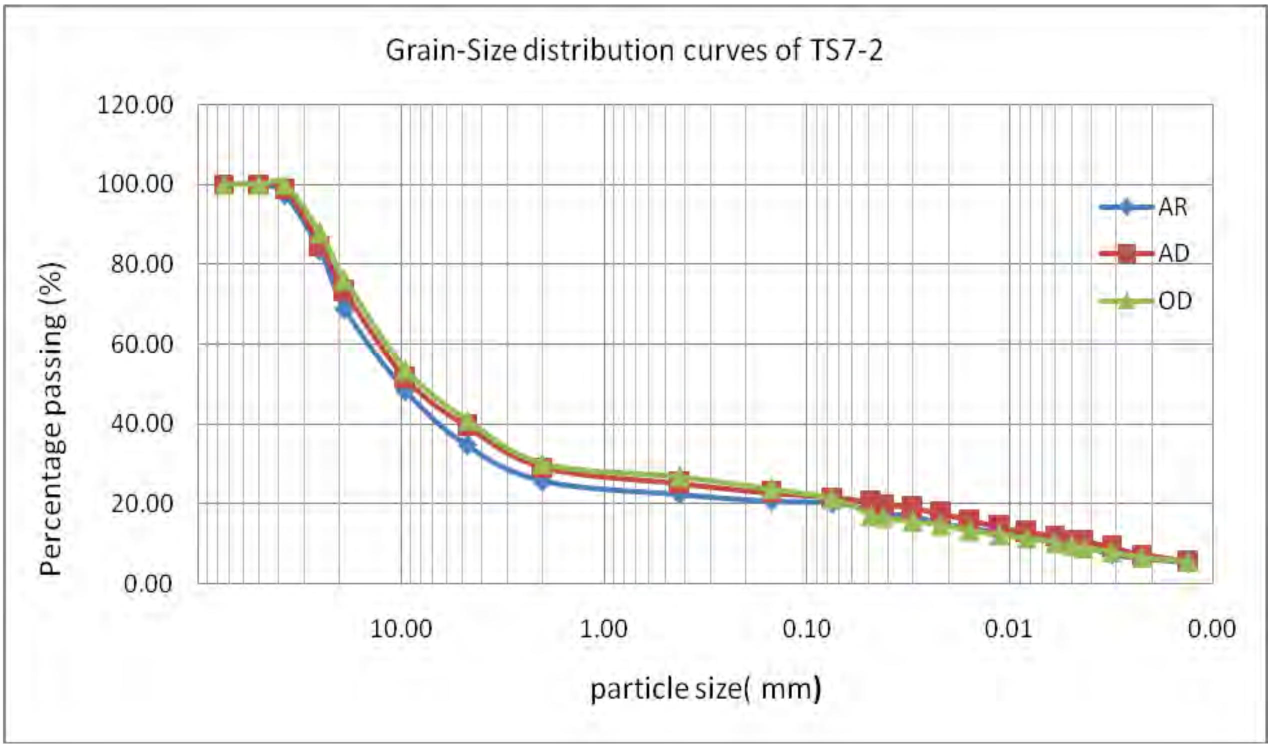
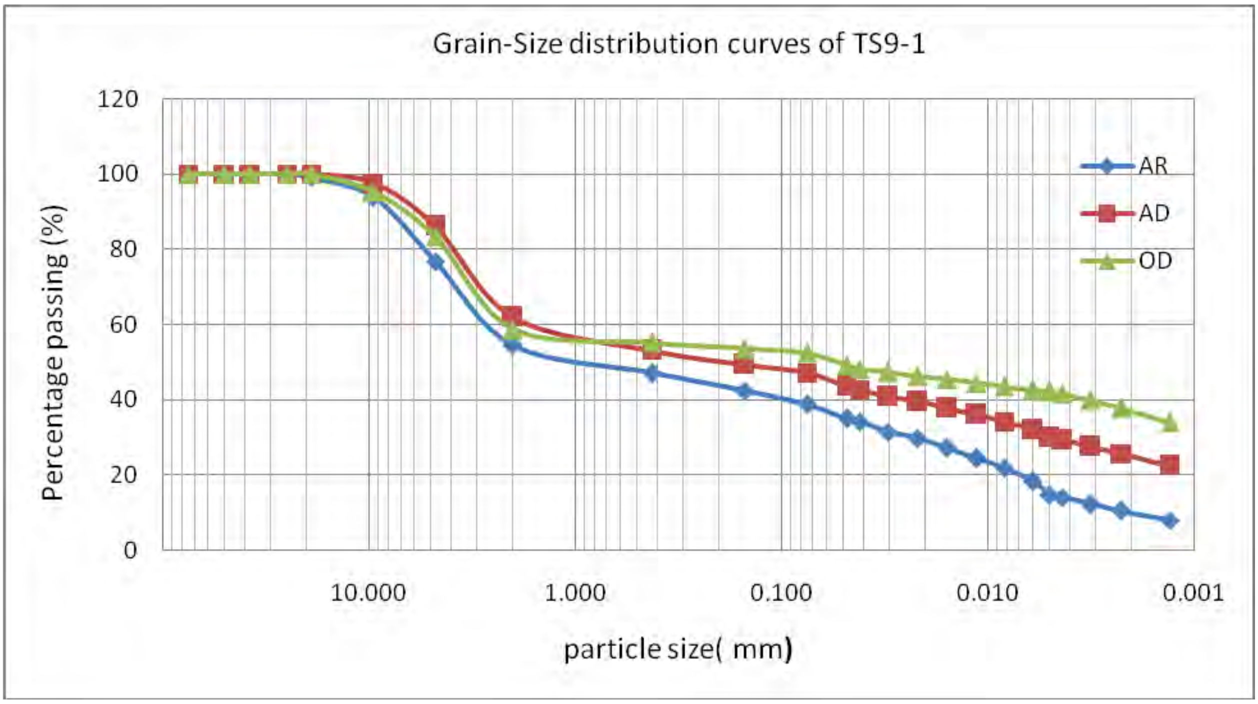


Figure B - 3 Grain-Size distribution curves of test samples TS7-1 & TS7-2



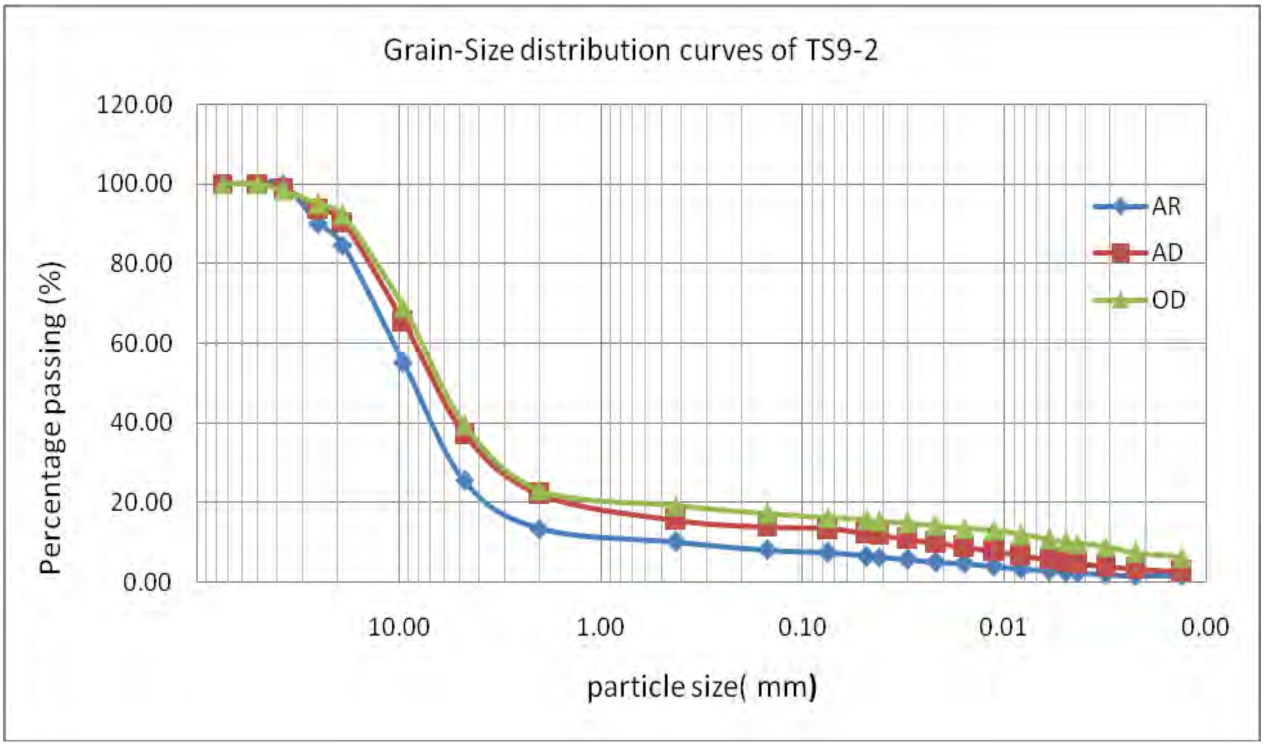


Figure B - 4 Grain-Size distribution curves of test samples TS9-1 & TS9-2

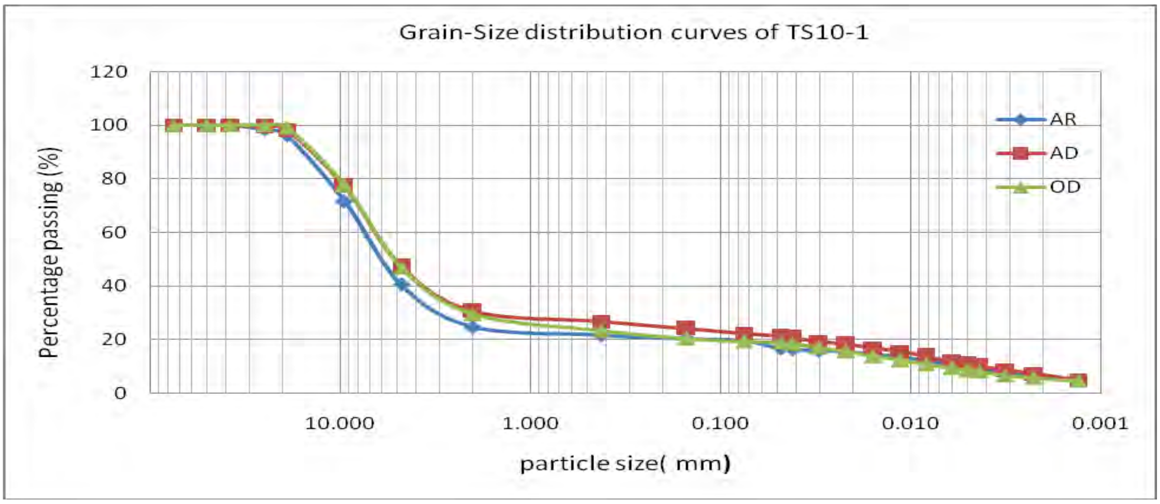


Figure B - 5 Grain-Size distribution curves of test samples TS10-1

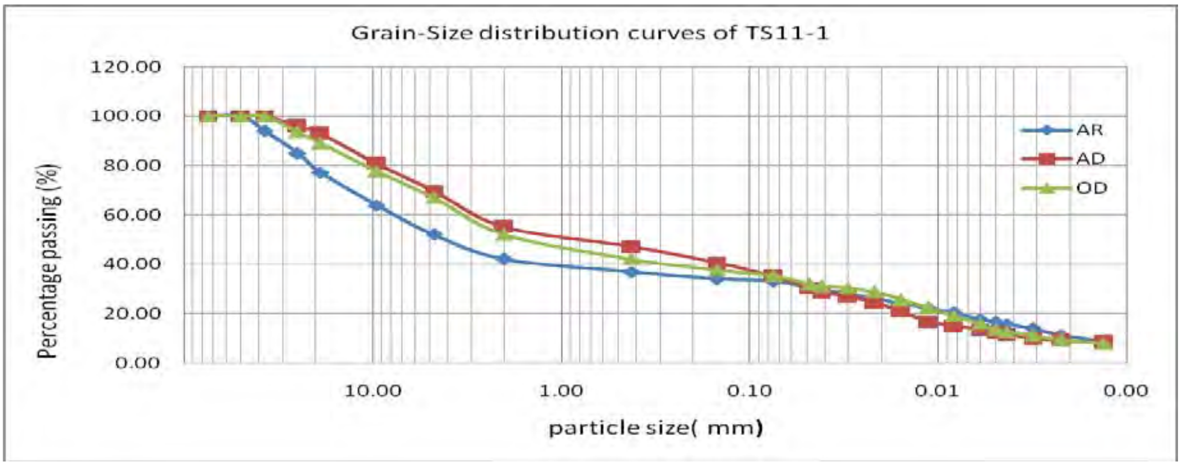


Figure B - 6 Grain-Size distribution curves of test samples TS11-1

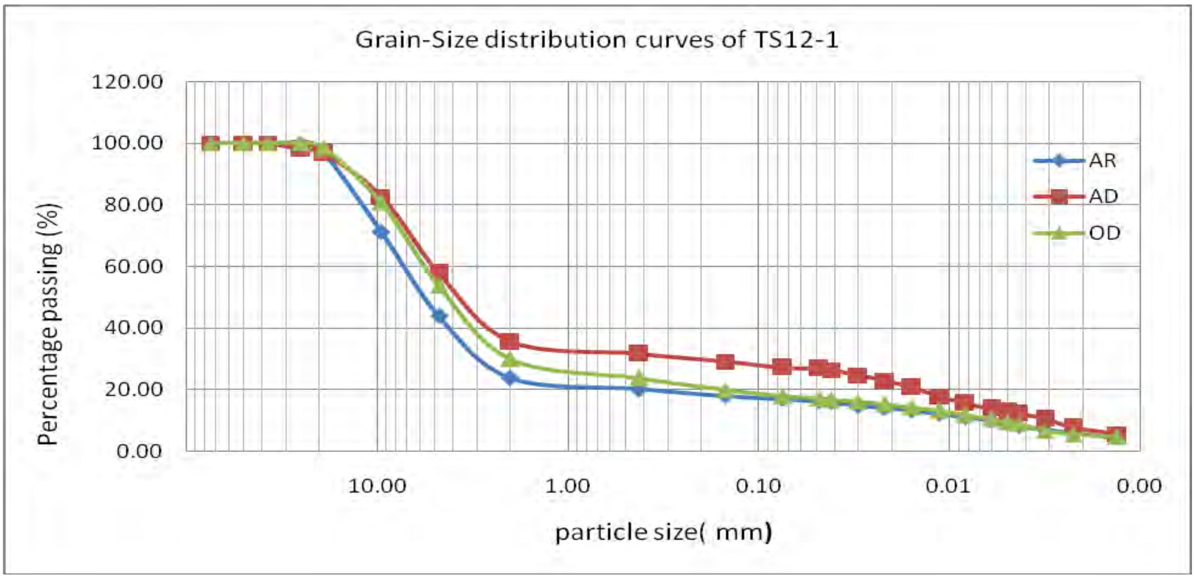


Figure B - 7 Grain-Size distribution curves of test samples TS12-1

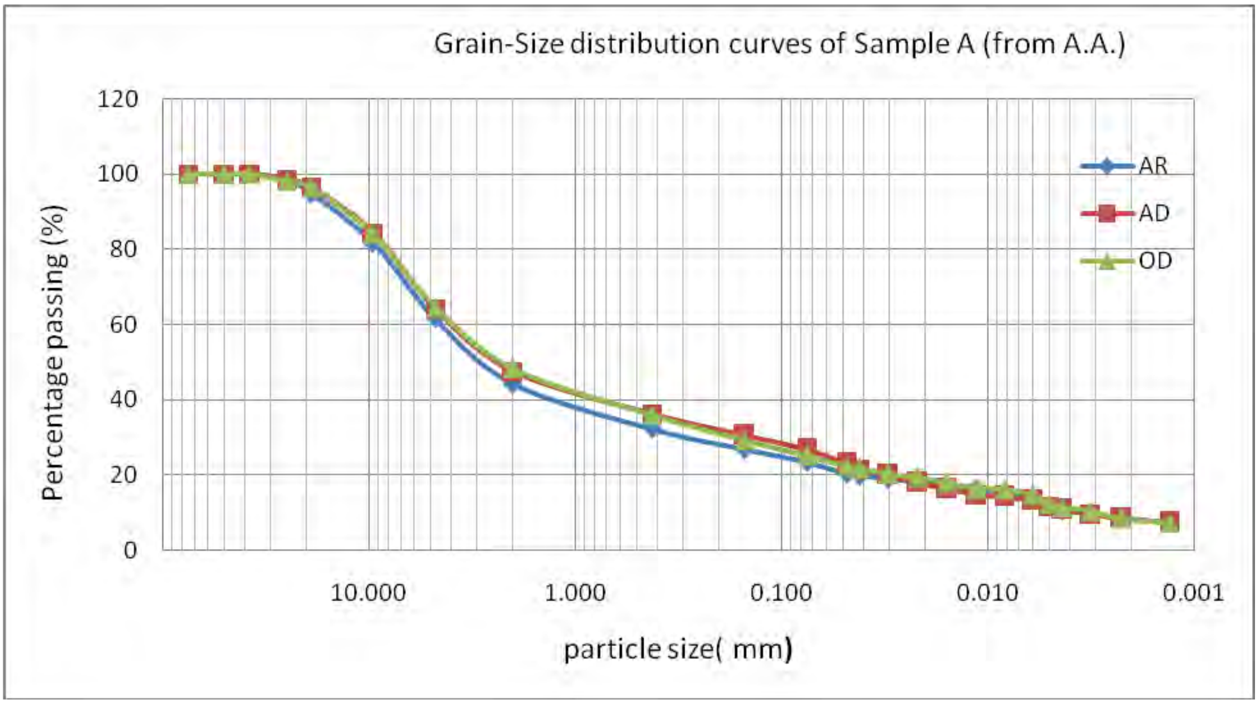


Figure B - 8 Grain-Size distribution curves of test sample 'Sample-A'

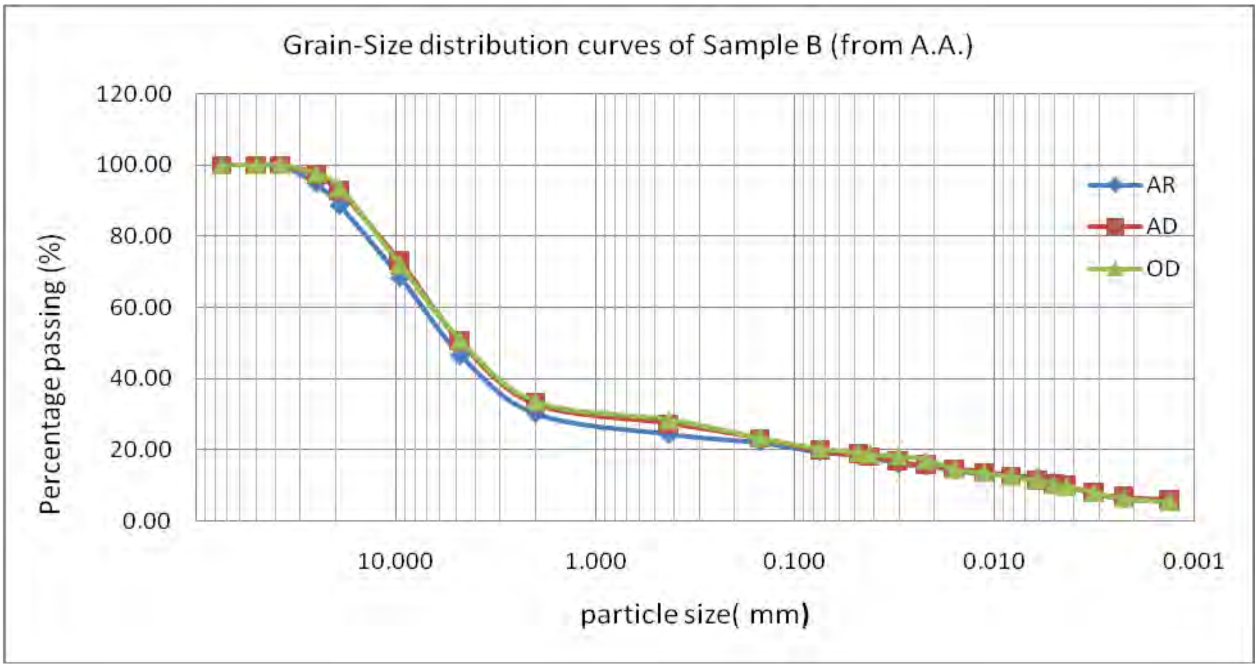
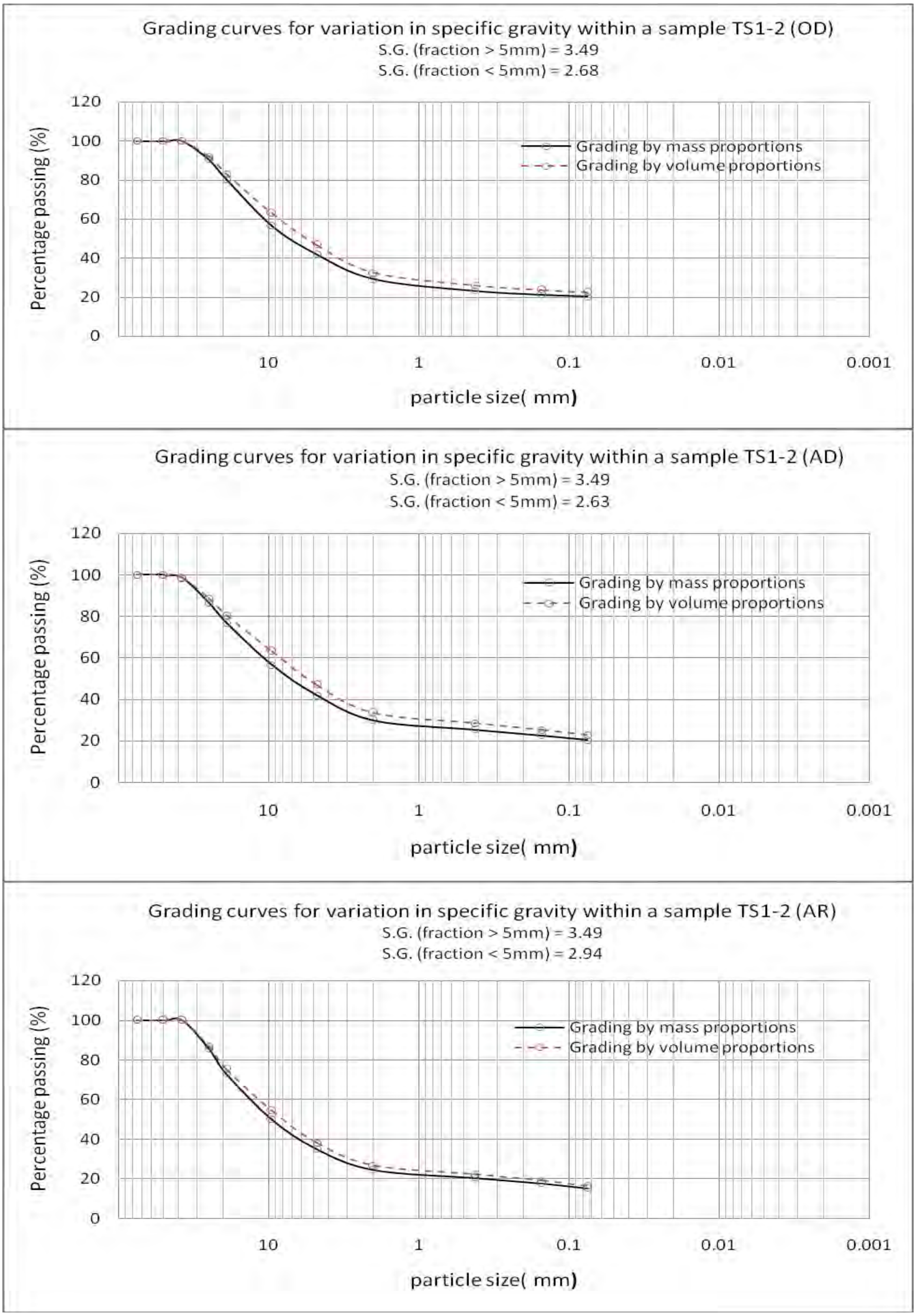


Figure B - 9 Grain-Size distribution curves of test sample 'Sample-B'

2. GRAIN-SIZE DISTRIBUTION CURVES FOR VARIATION IN SPECIFIC GRAVITY WITHIN A SAMPLE


Grading curves for variation in specific gravity within a sample TS1-2 (OD)

S.G. (fraction > 5mm) = 3.49

S.G. (fraction < 5mm) = 2.68

Grading curves for variation in specific gravity within a sample TS1-2 (AD)

S.G. (fraction > 5mm) = 3.49

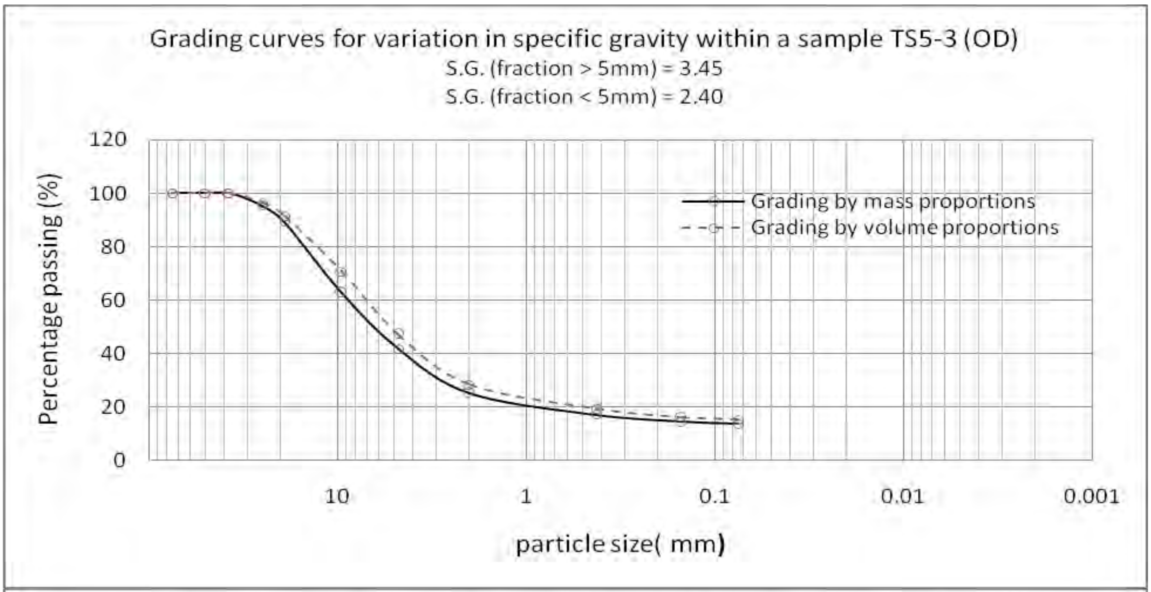
S.G. (fraction < 5mm) = 2.63

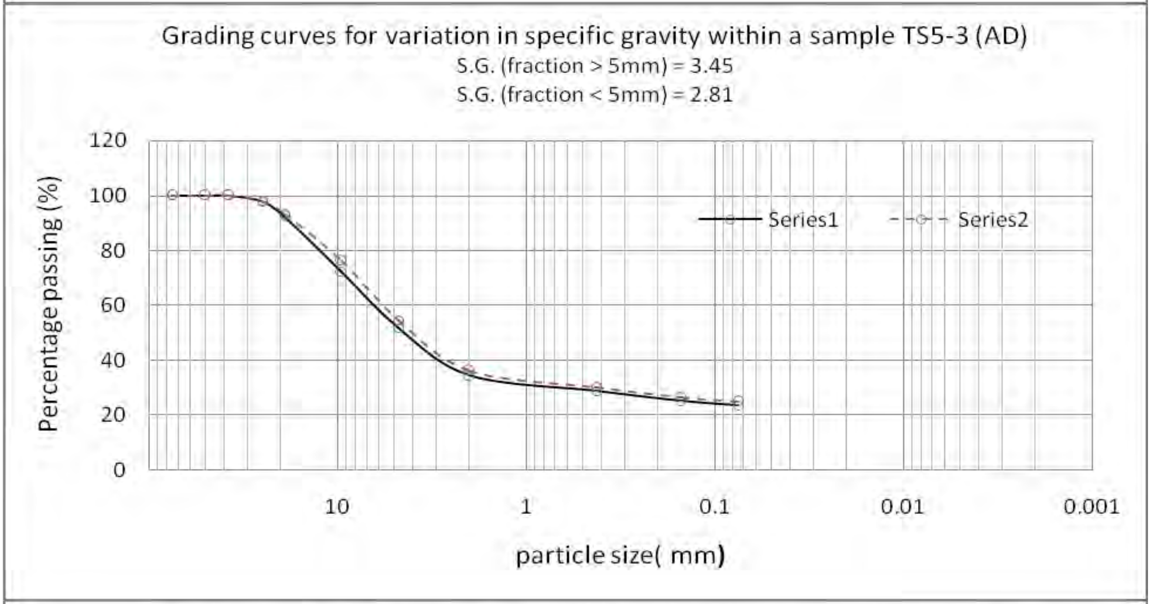
Grading curves for variation in specific gravity within a sample TS1-2 (AR)

S.G. (fraction > 5mm) = 3.49

S.G. (fraction < 5mm) = 2.94

Figure B - 10 grading curves for variation in specific gravity & sample pretreatments within sample TS1-2





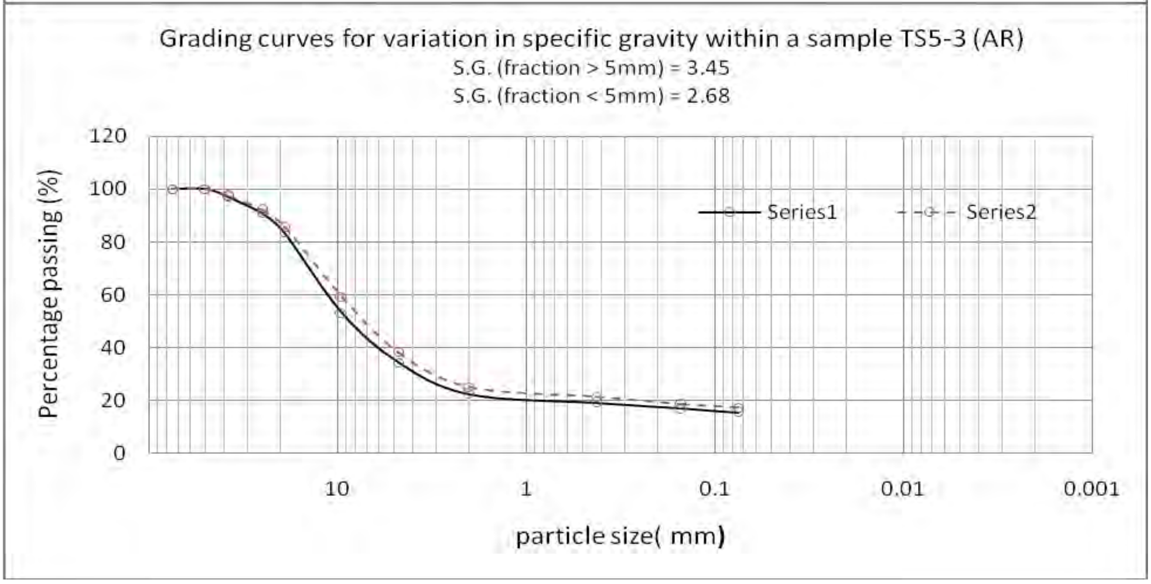


Figure B - 11 grading curves for variation in specific gravity & sample pretreatments within sample TS5-3

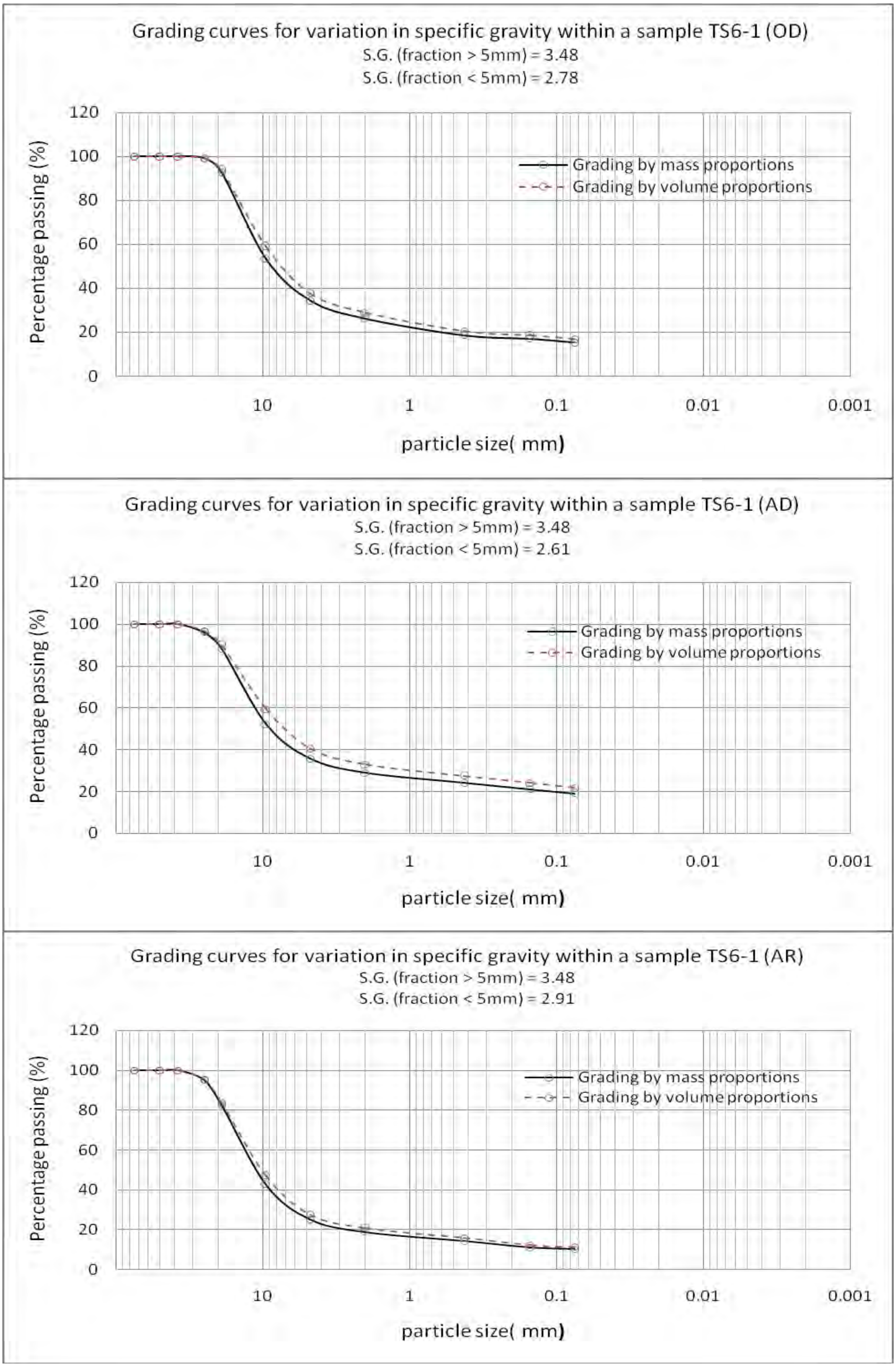
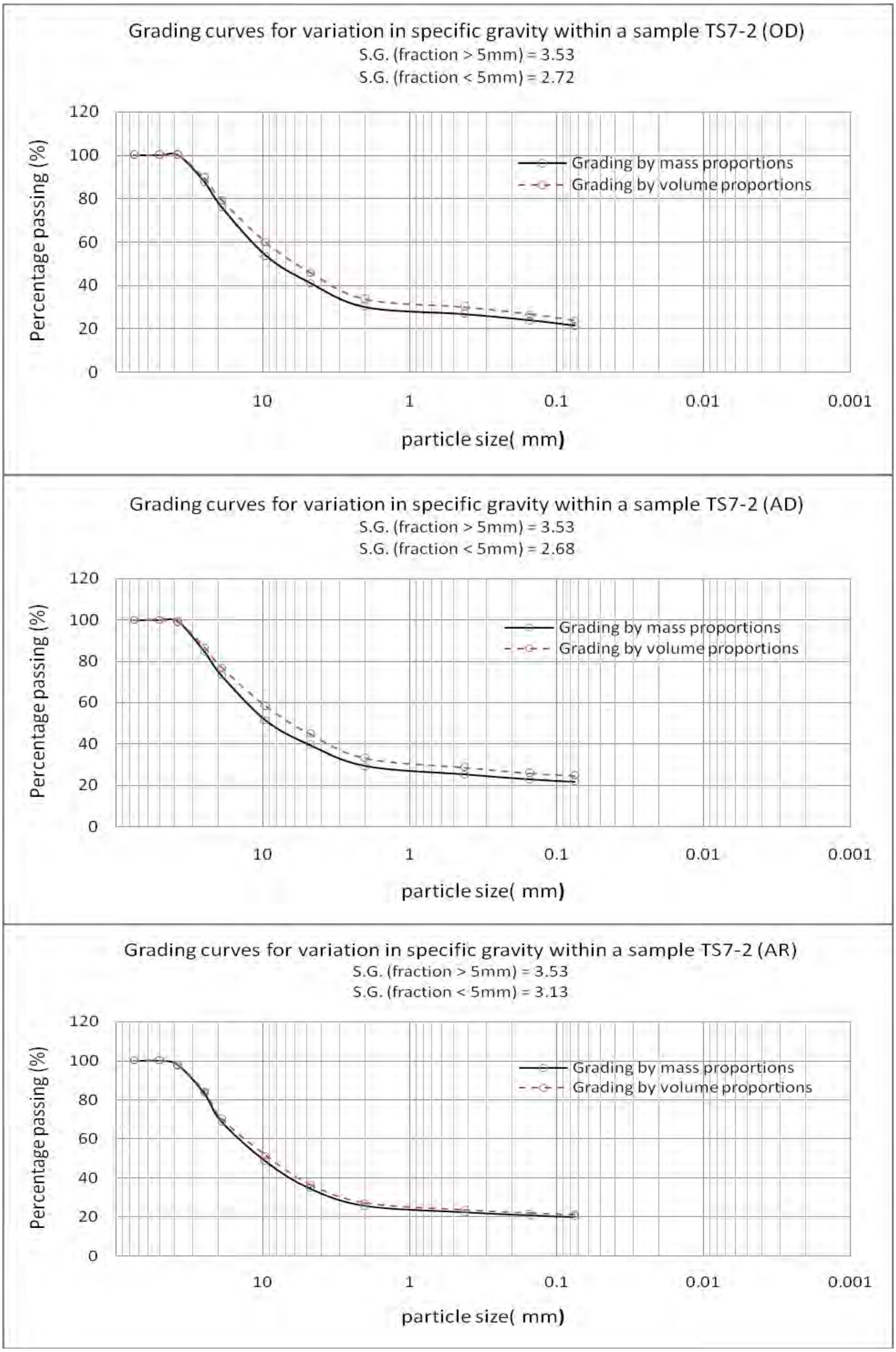


Figure B - 12 grading curves for variation in specific gravity & sample pretreatments within sample TS6-1



Grading curves for variation in specific gravity within a sample TS7-2 (OD)

S.G. (fraction > 5mm) = 3.53

S.G. (fraction < 5mm) = 2.72

Grading curves for variation in specific gravity within a sample TS7-2 (AD)

S.G. (fraction > 5mm) = 3.53

S.G. (fraction < 5mm) = 2.68

Grading curves for variation in specific gravity within a sample TS7-2 (AR)

S.G. (fraction > 5mm) = 3.53

S.G. (fraction < 5mm) = 3.13

Figure B - 13 grading curves for variation in specific gravity & sample pretreatments within sample TS7-2

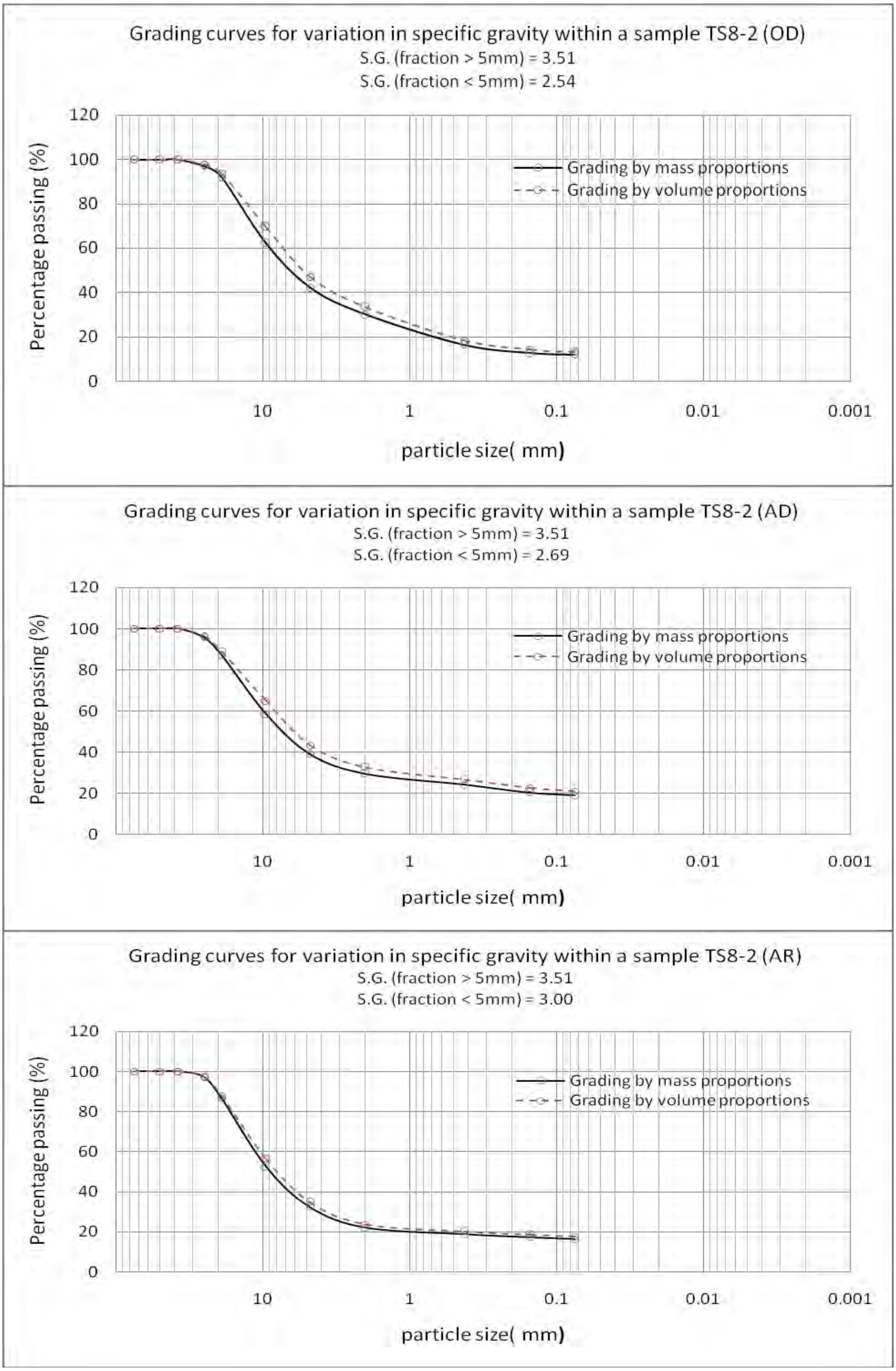


Figure B - 14 grading curves for variation in specific gravity & sample pretreatments within sample TS8-2

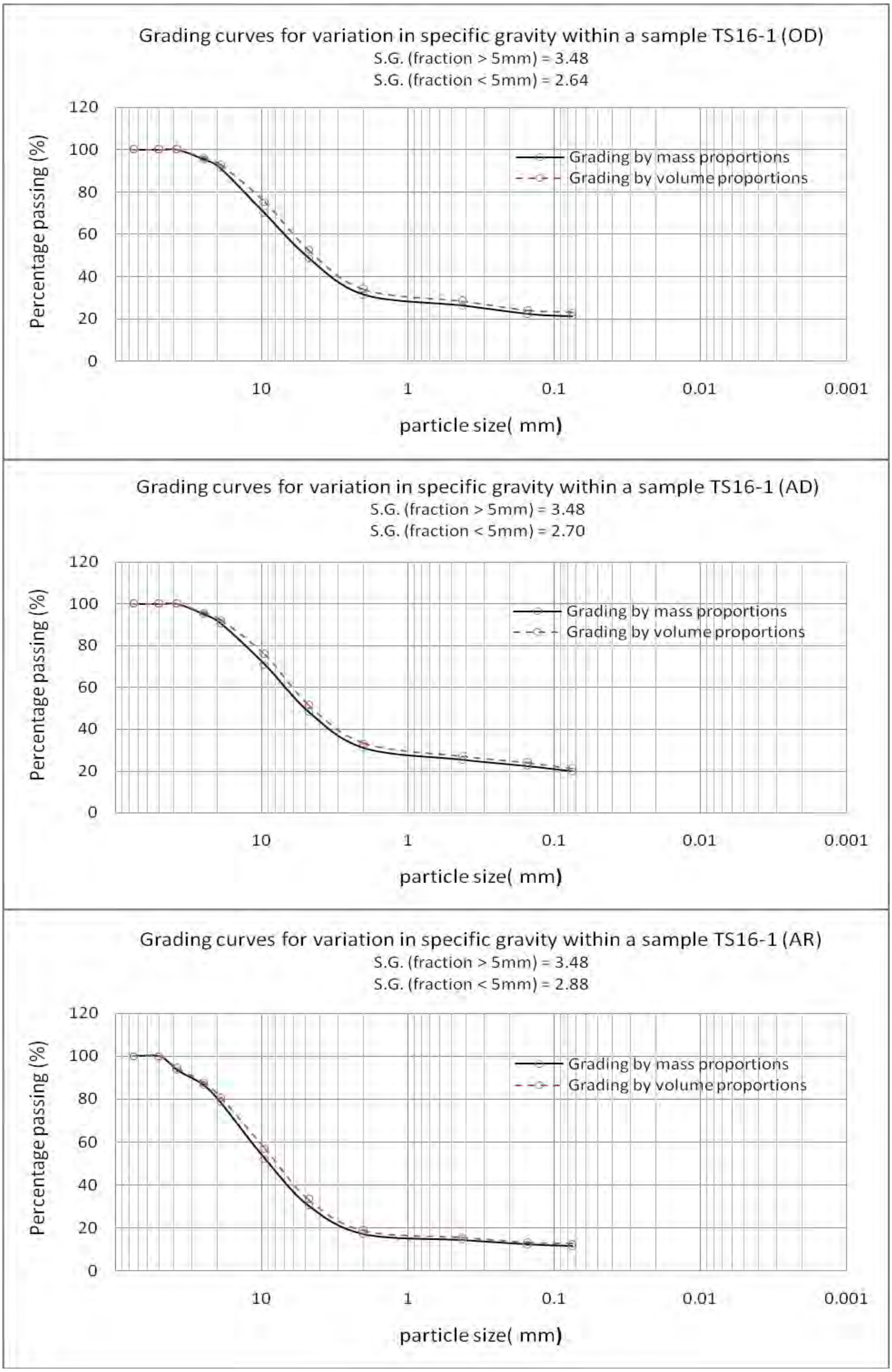


Figure B - 15 grading curves for variation in specific gravity & sample pretreatments within sample TS16-1

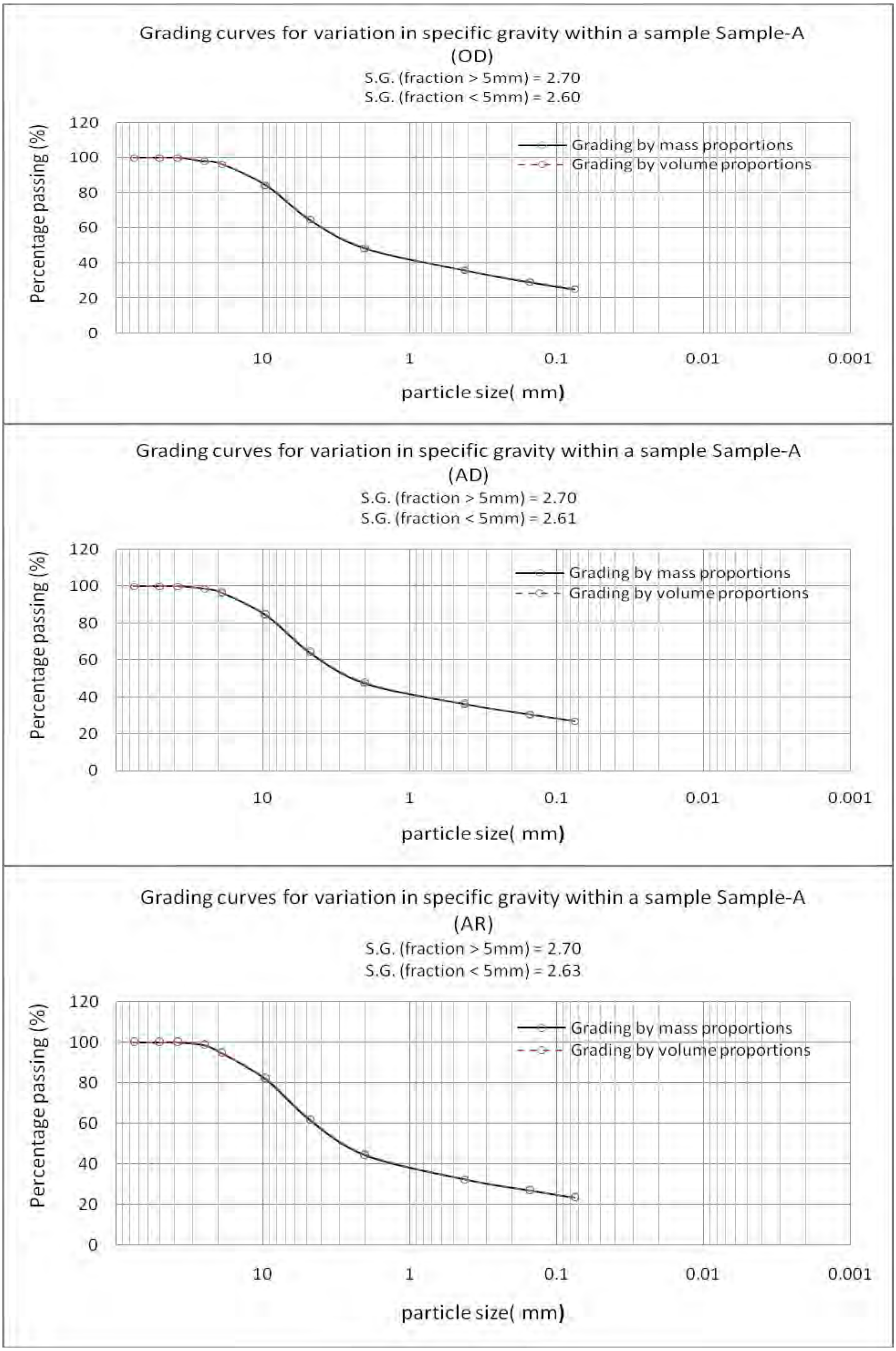
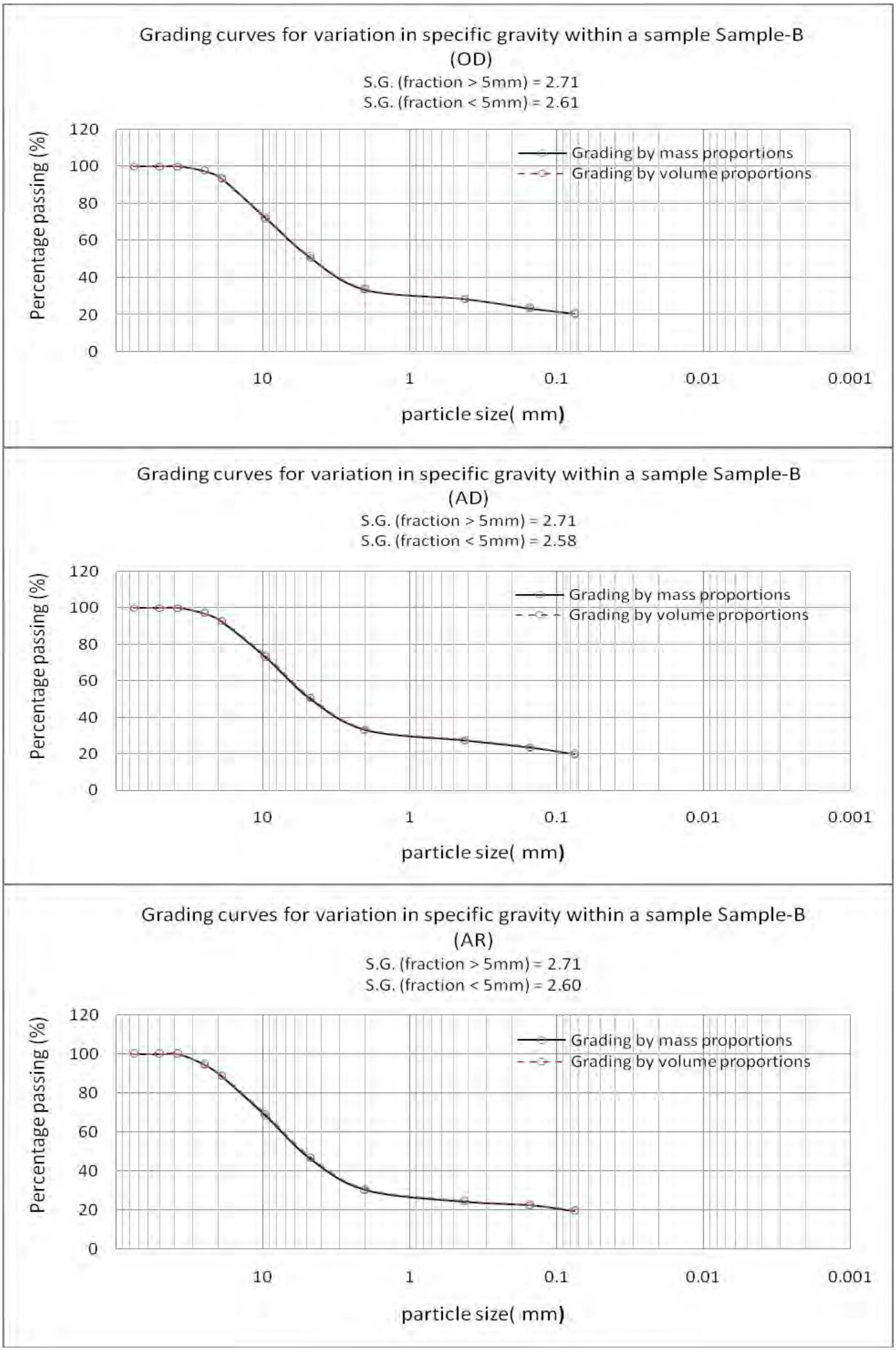


Figure B - 16 grading curves for variation in specific gravity & sample pretreatments within sample-A (non-lateritic soil)



Grading curves for variation in specific gravity within a sample Sample-B (OD)

S.G. (fraction > 5mm) = 2.71
S.G. (fraction < 5mm) = 2.61

Grading curves for variation in specific gravity within a sample Sample-B (AD)

S.G. (fraction > 5mm) = 2.71
S.G. (fraction < 5mm) = 2.58

Grading curves for variation in specific gravity within a sample Sample-B (AR)

S.G. (fraction > 5mm) = 2.71
S.G. (fraction < 5mm) = 2.60

Figure B - 17 grading curves for variation in specific gravity & sample pretreatments within sample-B (non-lateritic soil)

3. GRAIN-SIZE DISTRIBUTION CURVES FOR VARIATION IN SAMPLE LOCATIONS /DEPTHS/

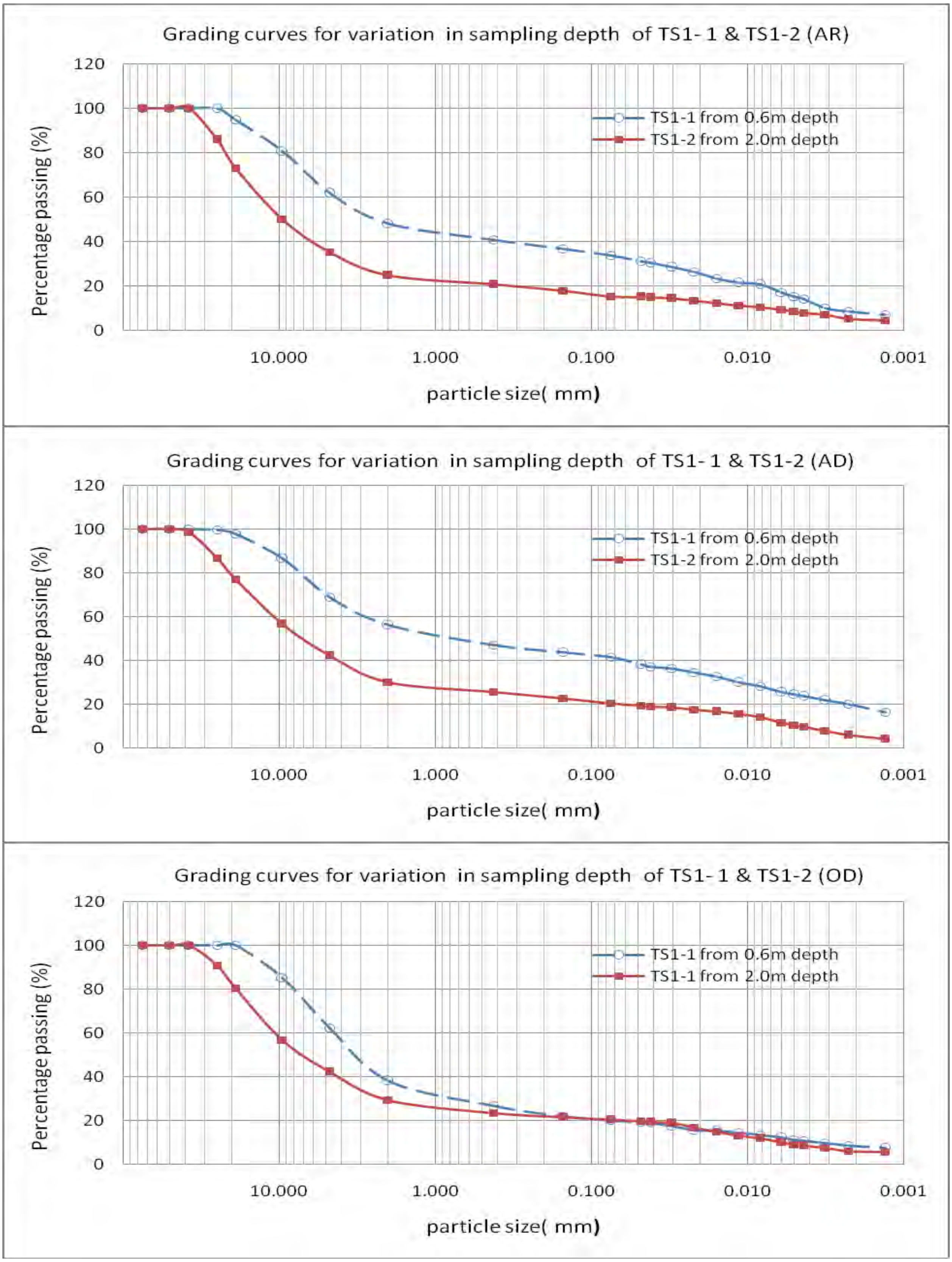
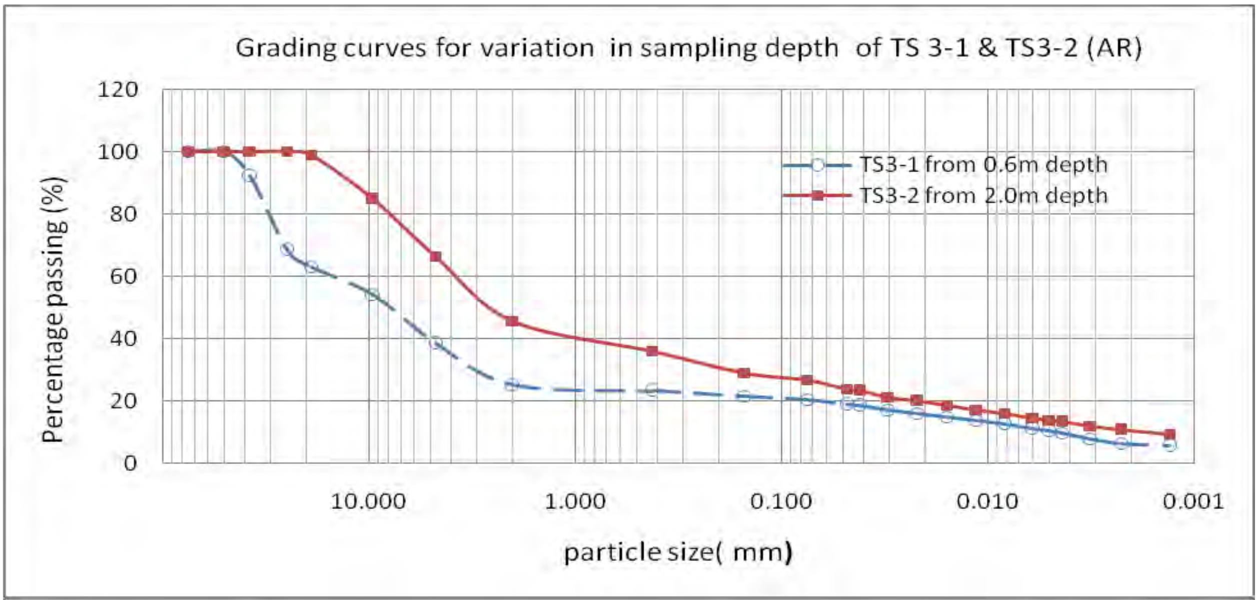
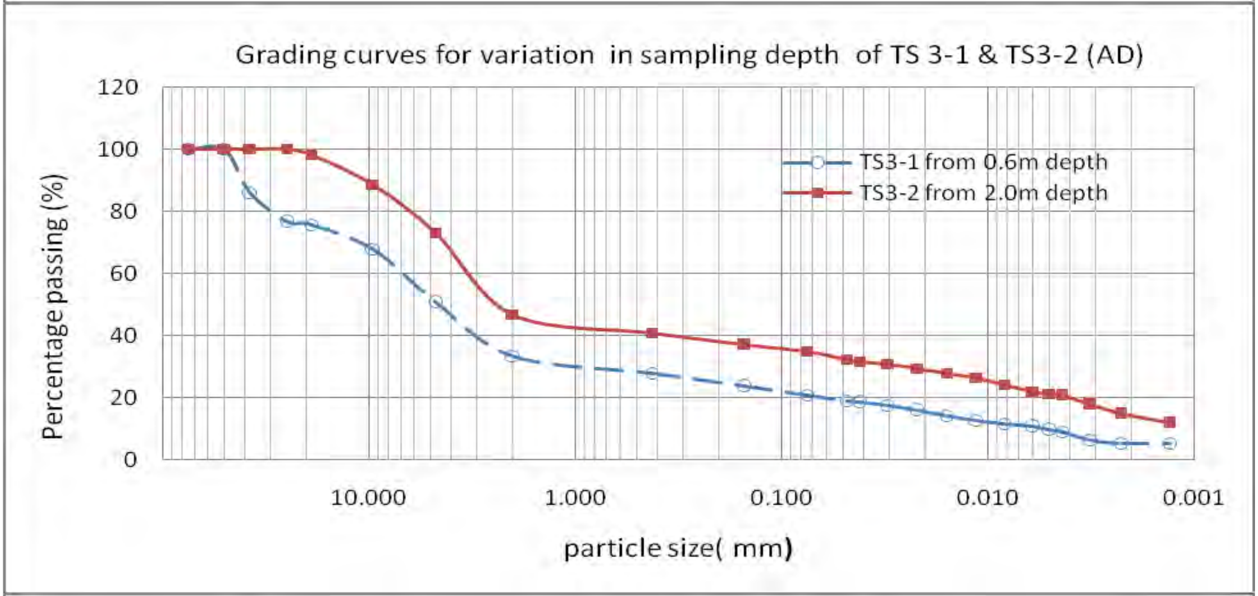


Figure B - 18 grading curves for variation in sampling depth & sample pretreatments within samples TS1-1 & TS1-2





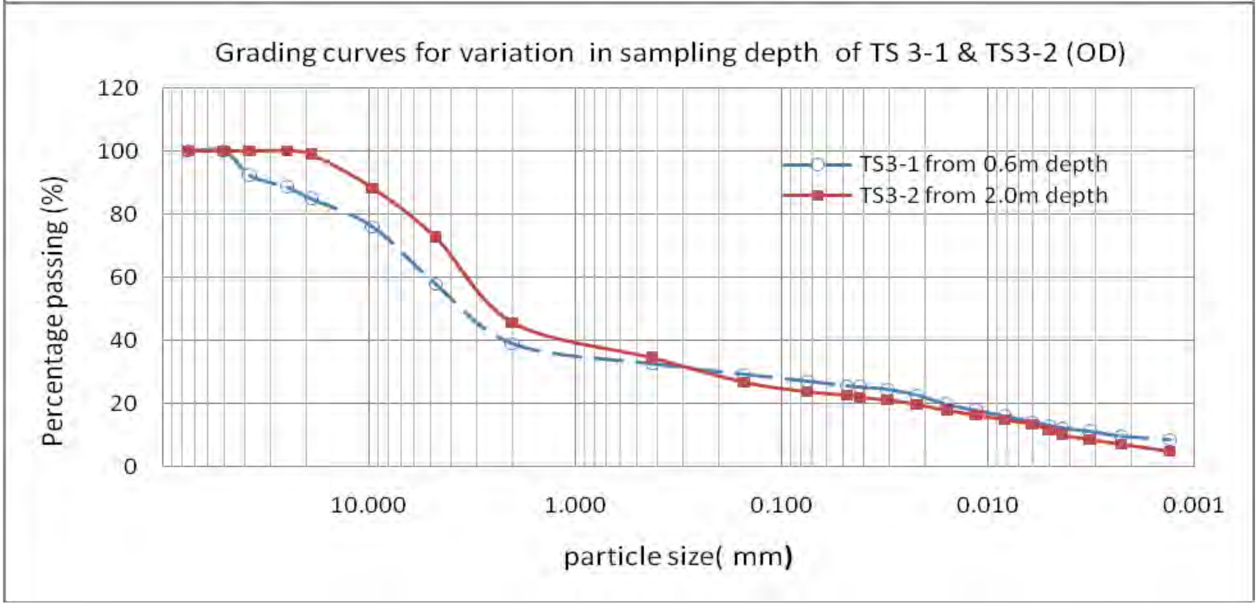


Figure B - 19 grading curves for variation in sampling depth & sample pretreatments within samples TS3-1 & TS3-2

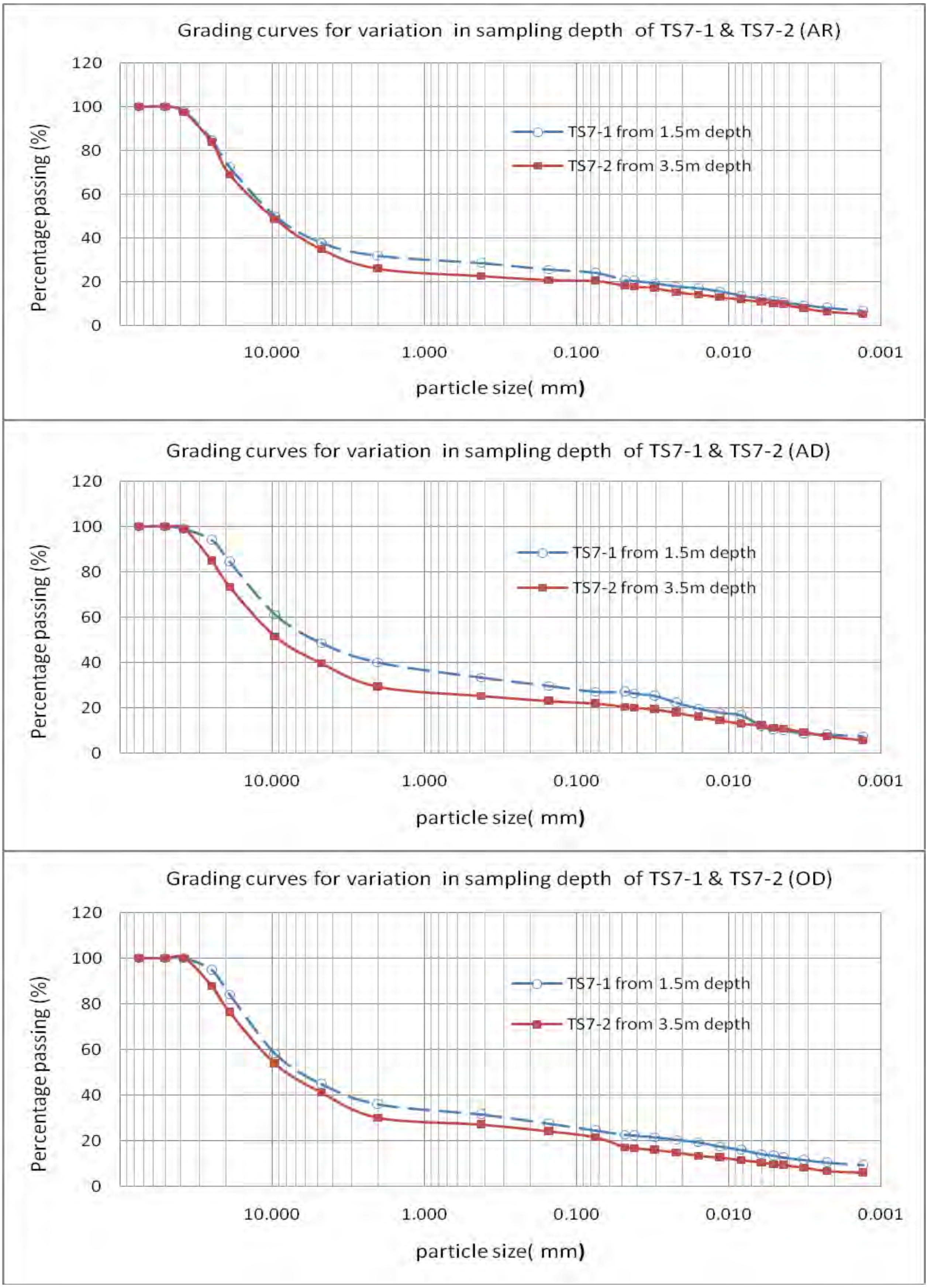


Figure B - 20 grading curves for variation in sampling depth & sample pretreatments within samples TS7-1 & TS7-2

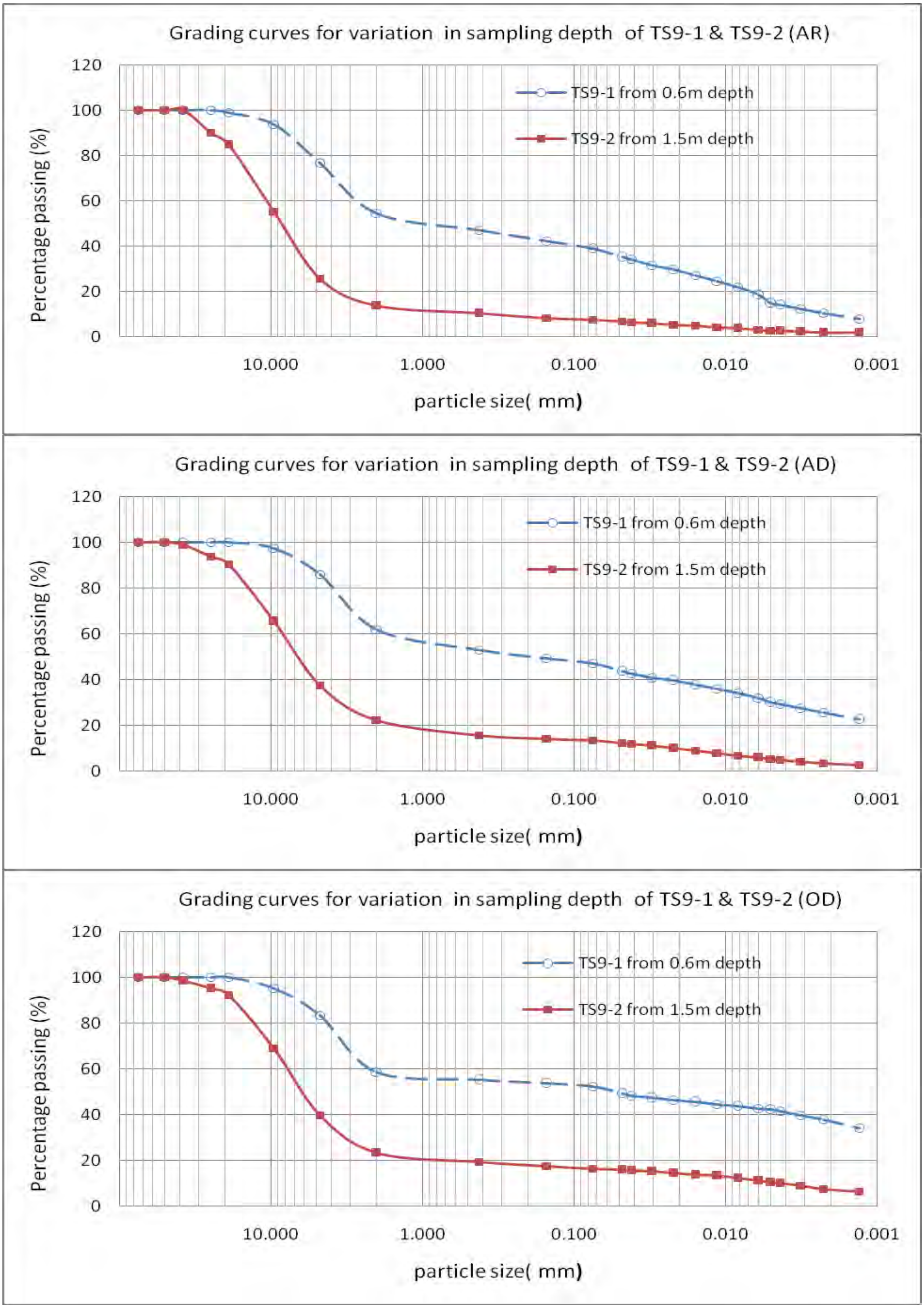


Figure B - 21 grading curves for variation in sampling depth & sample pretreatments within samples TS9-1 & TS9-2

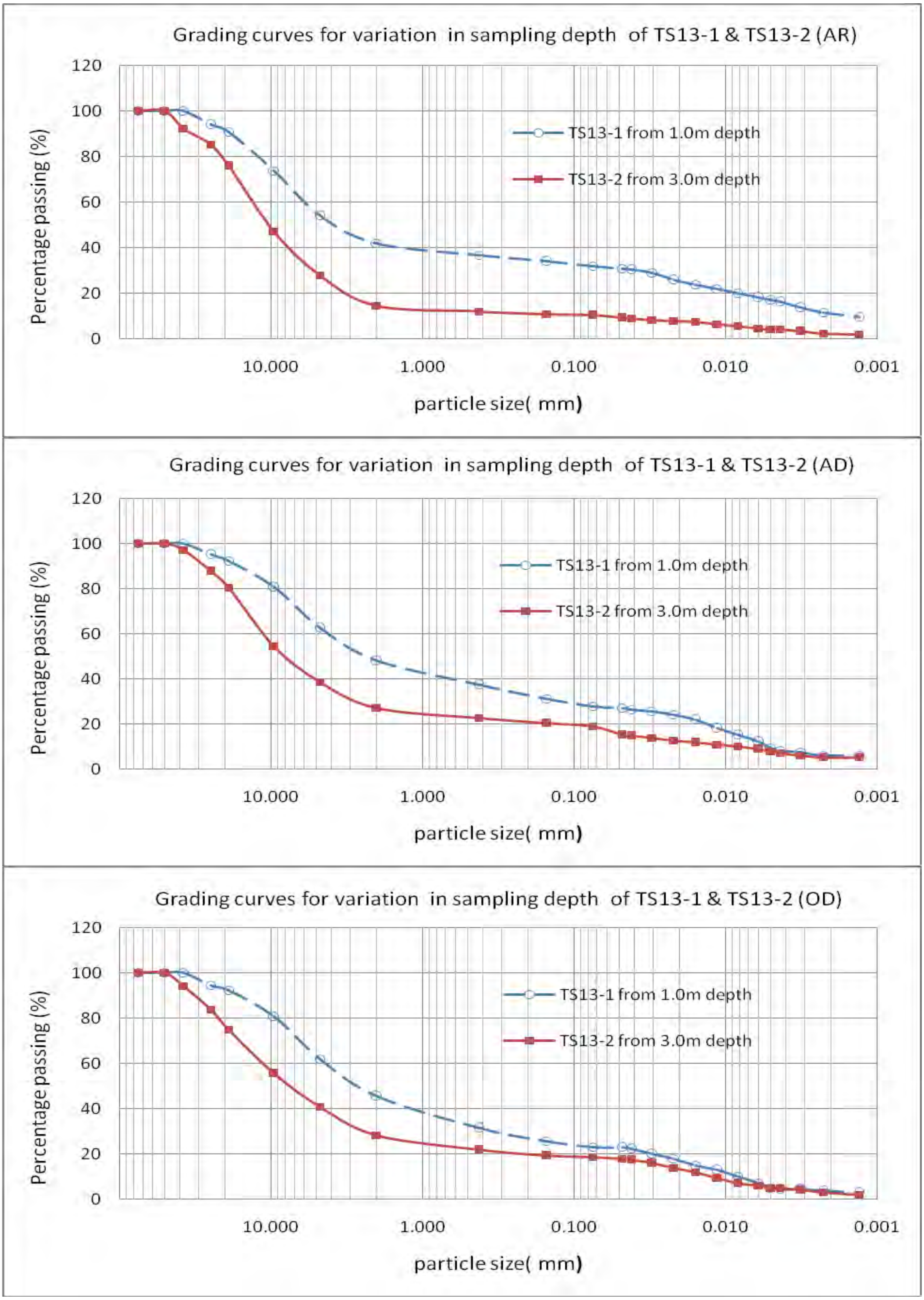


Figure B - 22 grading curves for variation in sampling depth & sample pretreatments within samples TS13-1 & TS13-2

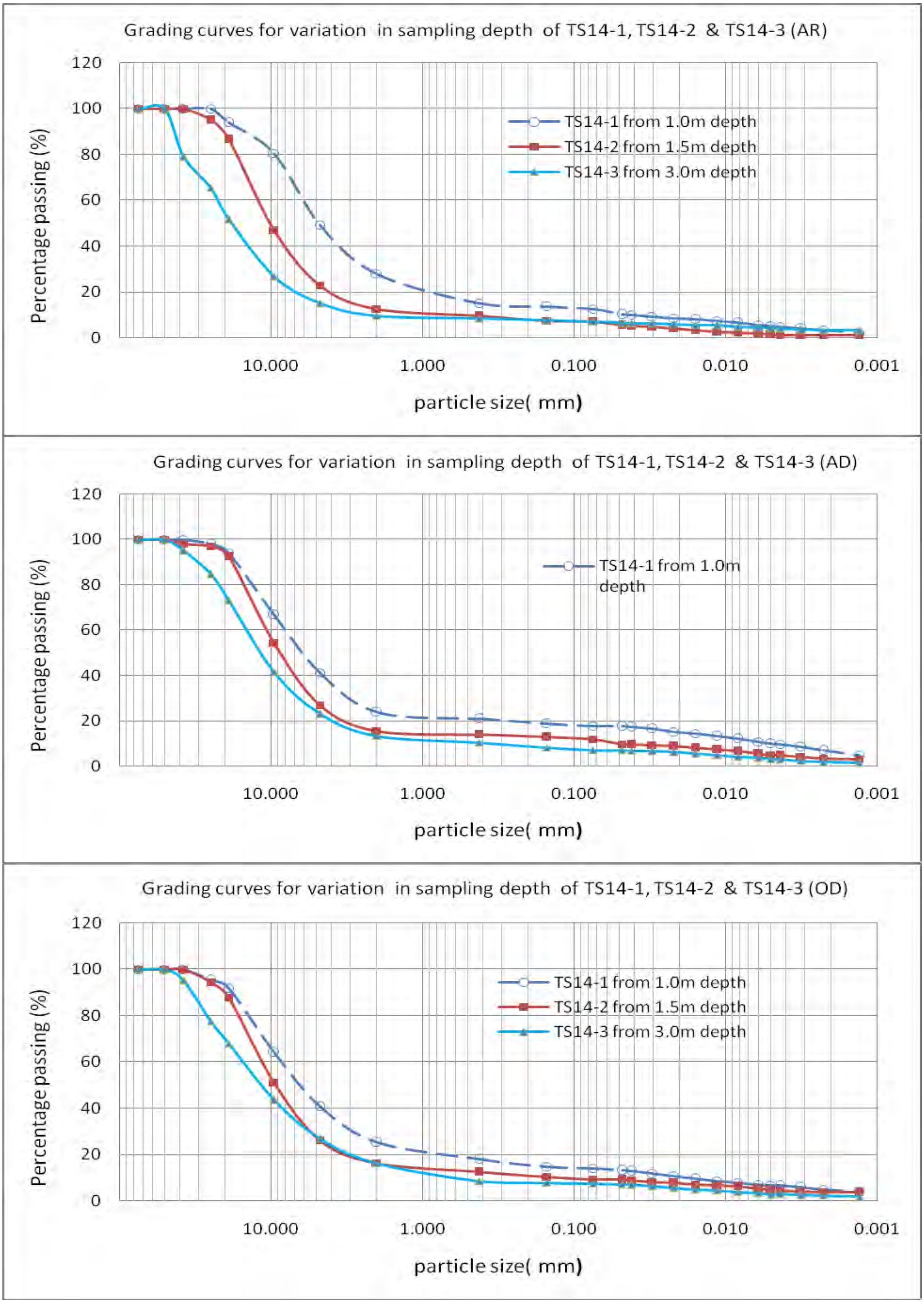


Figure B - 23 grading curves for variation in sampling depth & sample pretreatments within samples TS14-1, TS14-2 & TS14-3

4. RANGE OF GRAIN-SIZE DISTRIBUTION CURVES FOR DIFFERENT PRETREATMENTS /TESTING PROCEDURES/

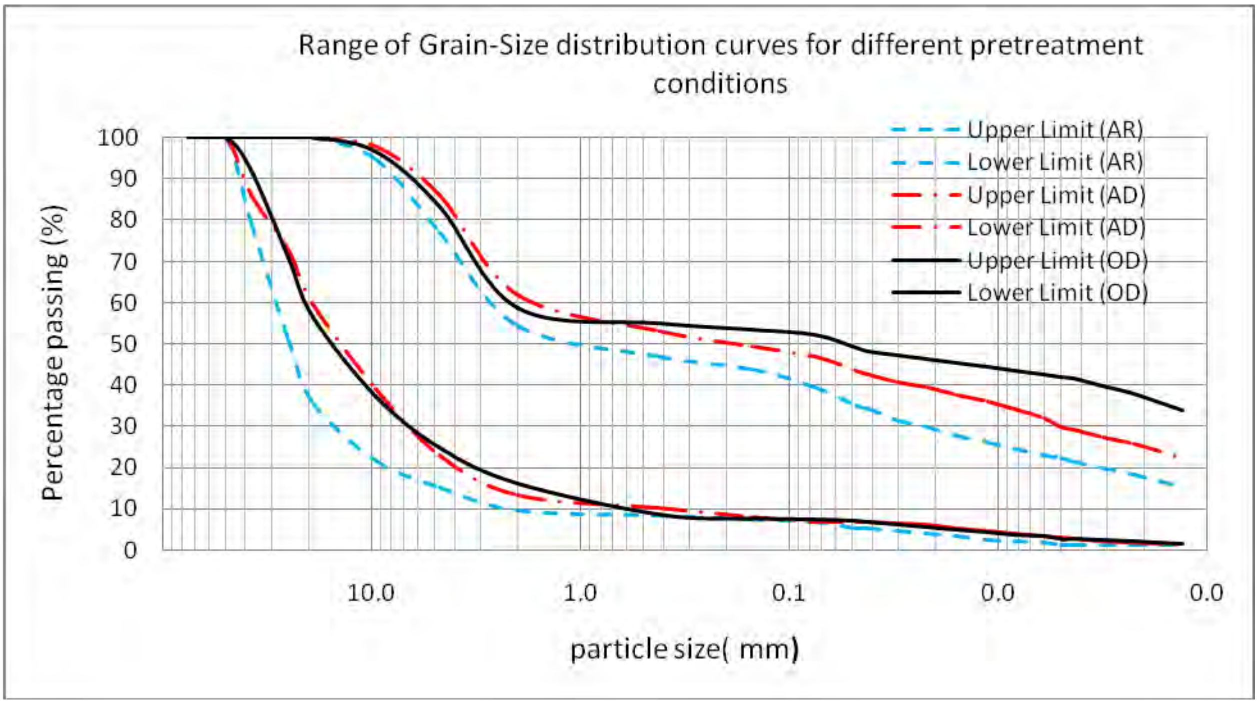


Figure B - 24 Ranges of grain-Size distribution curves of AR, AD & OD samples

5. AVERAGE GRAIN-SIZE DISTRIBUTION CURVES FOR DIFFERENT PRETREATMENTS /TESTING PROCEDURES/

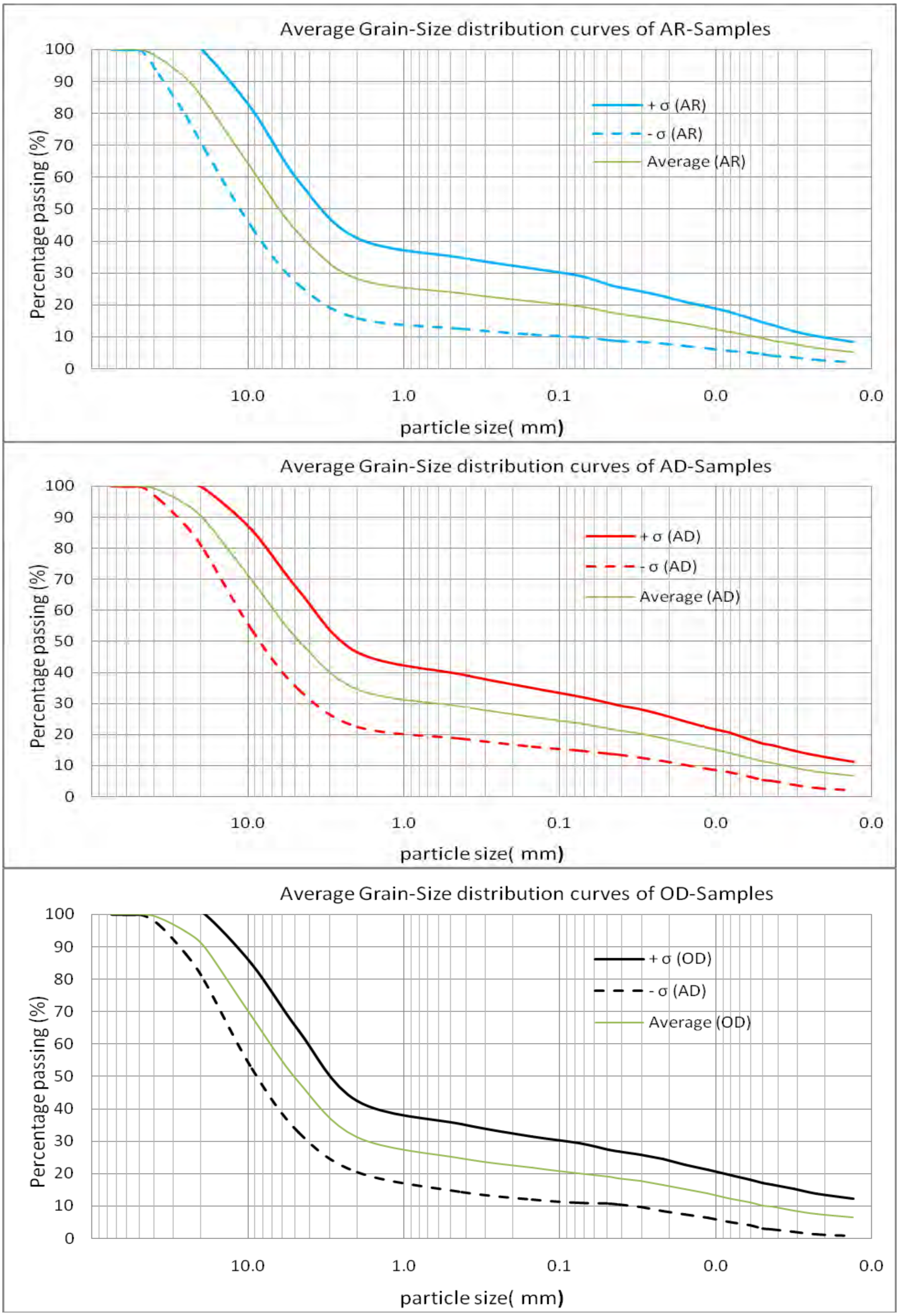


Figure B - 25 Average grain size distribution curves

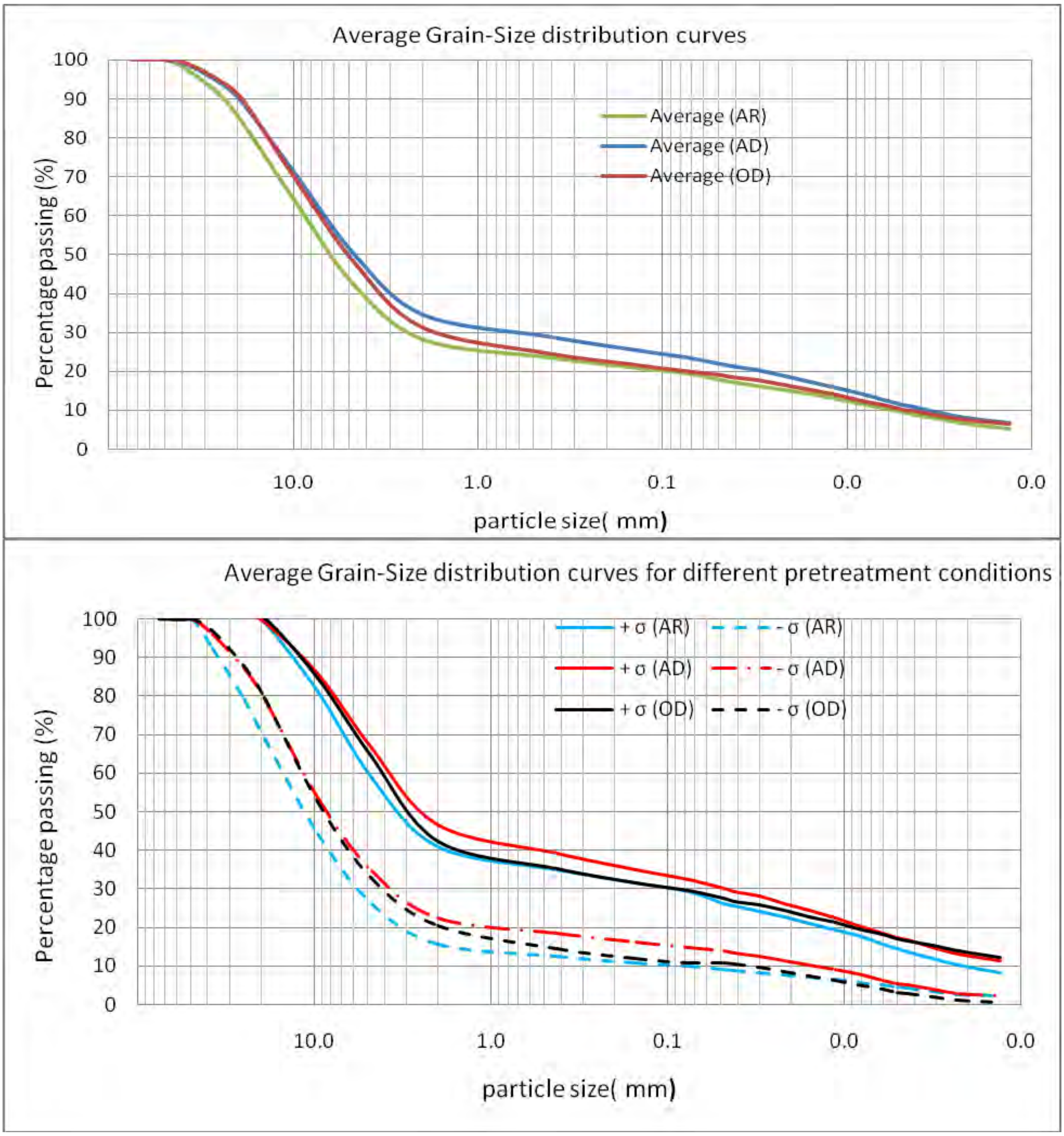


Figure B - 26 Average grain size distribution curves