ASSESSMENT OF THE QUALITY OF TEST RESULTS FROM SELECTED CIVIL ENGINEERING MATERIAL TESTING LABORATORIES IN TANZANIA

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ABSTRACT

Civil and geotechnical engineering material testing laboratories are expected to produce accurate and reliable test results. However, the ability of laboratories to produce accurate and reliable test results depends on many factors, among others, the competence of laboratory technicians, adherence to test procedures, as well as the condition of equipment. This paper assesses the quality of test results obtained from five selected civil and geotechnical engineering material testing laboratories in Tanzania. Three soil samples commonly found on construction sites in Tanzania were sampled and submitted to the selected five laboratories that were requested to perform the foundation indicator tests (particle size distribution, liquid limit and plastic limit). The test results from each of the five selected laboratories were analysed and compared, and thus demonstrated both the extent to which test results from different laboratories can vary and the impact that such variance has on the design of infrastructure. The assessments also highlighted the importance of laboratory accreditation and proficiency testing. To improve the quality of the results, laboratory accreditation and the implementation of a compulsory proficiency testing scheme for civil and geotechnical engineering material testing laboratories in Tanzania are recommended.

Keywords: Accreditation, Accuracy, Foundation Indicator Tests, Material Testing, Proficiency Testing, Reliable.

1 INTRODUCTION

Infrastructure development is one of the key pillars for the realisation of economic growth of any country. Many infrastructure projects, including transport (i.e. roads, railways, airport and ports), energy facilities, manufacturing plants and water supply are currently being undertaken in Tanzania or planned to start in the near future. To ensure that infrastructure projects are successfully implemented, civil and geotechnical engineering material testing laboratories play a critical role in the design, construction, operation and maintenance of such infrastructure. Material testing is required not only to ensure compliance with the quality standards, but also to realise the value for money of the infrastructure projects.

Civil and geotechnical engineering material testing laboratories play a crucial in the construction industry. Material testing is performed during various stages of construction, and the test results are used for various purposes. For instance, soil test results are used during the design stage to predict the behaviour of geotechnical structures subjected to static or dynamic loading. Therefore, it is important for the material testing laboratories to produce accurate and reliable results to ensure the optimum design and performance of such structures.

The ability of laboratories to produce accurate and reliable test results are affected by several factors, including the quality of the test equipment, adherence to test methods or procedures, as well as the competence of laboratory personnel. As a means of ensuring good quality of test results, laboratory accreditation has become a standard procedure within the civil engineering industry (ISO 17025, 2010; SANS 17025, 2010). Once a laboratory has been accredited, quality control and quality assurance schemes are implemented by accreditation bodies to ensure that the laboratories continue to produce good quality test results. Most of the accreditation bodies use a proficiency testing scheme (inter-laboratory comparison) as a tool for checking laboratory testing performance (SABITA, Softic et al., 2012; ISO 17043, 2010; SANS, 17043, 2010; Jacobsz and Day, 2008).

The objective of the study was to present outcomes of the assessment of the quality of test results from selected civil and geotechnical engineering material testing laboratories in Tanzania by means of inter-laboratory comparison.

2 OVERVIEW OF LABORATORY ACCREDITATION AND PROFICIENCY TESTING

2.1 Laboratory Accreditation

Laboratory accreditation is a means of determining the technical competence of a laboratory to perform specific types of testing, measurement and calibration (ISO 17025, 2010; SANS 17025, 2010). It is set to ensure that laboratory users obtain reliable test results and measurements, and render calibration services that will enable them to meet users' needs. Accreditation also provides laboratories recognition for their services and ensures that laboratory technical competencies are maintained over time.

2.2 Proficiency Testing

Proficiency testing (also known as inter-laboratory comparison) is used for several purposes: evaluating the performance of laboratories; identifying problems in laboratories as well as inter-laboratory differences; and establishing the effectiveness and compatibility of test methods (ISO 17043, 2010; SANS, 17043, 2010; Grieve, 2002; Nielsen, 2002). An important part of proficiency testing is to determine the reference value of the measurement and the associated uncertainty. A question that is often put forward when comparing the test results obtained from different laboratories concerns the true value of the particular measurement. As such, the understanding of the two concepts known as accuracy and precision is crucial. According to Dunnicliff (1988), accuracy is defined as the closeness of a measurement to the true value of the quantity measured, whereas precision is the closeness of each of a number of similar measurements to the arithmetic mean (as illustrated in Figure 1).

The laboratory should first attempt to obtain the accurate results with high precision or repeatability. In the absence of the true value, the proficient testing scheme can use different methods to establish the true value. According to Nielsen (2002), the term proficiency testing is used to cover two different processes. The first is used mostly in the testing community, where similar samples are submitted to participating laboratories for testing. In this case one has to make sure that the samples distributed are homogeneous, in other words that they are essentially the same. The second process is used primarily in the calibration community, where one artefact or dummy specimen is circulated among the participating laboratories. In this case, the key concern is that the artefact must prove to be stable throughout a testing round. Several studies have demonstrated that the successful implementation of a proficiency testing scheme will depend on certain factors, such as the homogeneity of the sample, given instructions, the reference value, and the evaluation process (Nielsen, 2002; Nielsen, 2003; Nielsen, 2004). The evaluation of the results of proficiency testing is often based on E_n value and the Z score (ISO 17043, 2010; SANS, 17043, 2010; Nielsen, 2002).

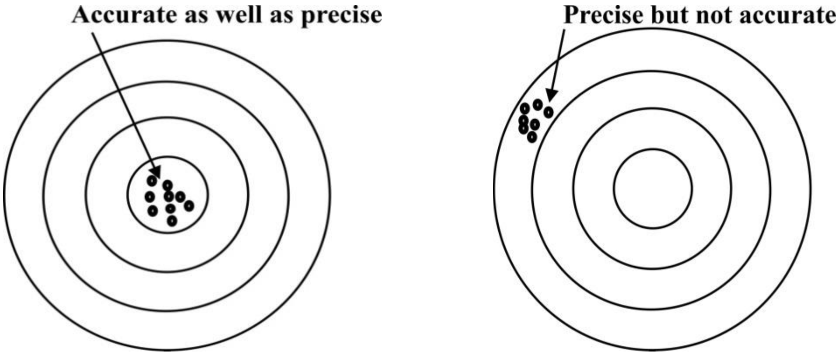

Figure 1. An illustration of accuracy and precision (Dunnicliff, 1988)

Although Tanzania is on the verge of an important industrialisation process, little effort is made to ensure that the civil and geotechnical engineering material testing laboratories provide accurate and reliable test results by implementing programmes such as proficiency testing. To give insight into the importance of proficiency testing, the authors investigated the question of whether geotechnical engineers get what they want from geotechnical laboratories available in Tanzania.

3 MATERIAL AND LABORATORY TESTING PROGRAMME

3.1 Materials and Sampling

The three soil samples that were used in the study included the following:

- Clay Sample 1 – sourced from a cement plant construction site in the Lindi region
- Clay Sample 2 – sourced from a power transmission tower construction site at Kitukutu in the Singida region
- Sand Sample – sourced from Mungu Maji sand quarry, the widely used sand source for infrastructure construction projects in the Singida region

During the material sampling, care was taken to ensure that the individual soil samples were identical. The bulk soil sample was first mixed thoroughly, and then rifled to obtain identical soil samples. The sampling procedure ensured that each laboratory received identical soil samples, hence reducing the variability of the test results caused by the samples not being identical.

3.2 Laboratory Selection

Five commercial civil and geotechnical engineering laboratories were selected to be used in the study. The selected laboratories are most widely used for testing soils for various construction projects in Tanzania. For the purposes of this paper, the identities of the laboratories will not be disclosed and they are merely defined as laboratories A, B, C, D and E throughout this paper. All the laboratories are frequently used for soil testing in Tanzania and they have been registered by the country's Engineers Registration Board (ERB).

3.3 Laboratory Testing Programme

The laboratory testing programme was conducted in three separate rounds. During the first round, Clay Sample 1 from a cement construction site in the Lindi region was submitted to the five selected laboratories. Each was requested to perform particle size distribution (sieve analysis by hydrometer analysis) and Atterberg limit (liquid limit and plastic limit) tests, which are the basic soil tests commonly referred to as foundation indicator tests. These tests are generally used to classify soils to assess the suitability of material to be used for construction and to ascertain soil design parameters for the foundation design.

After assessment of the test results of Clay Sample 1 obtained during the first round of laboratory testing, a second testing programme was designed to check consistency and verify the competency of the laboratories. Clay Sample 2 from Kitukutu in the Singida region was submitted to the same five laboratories that had performed the first-round tests (i.e. particle size distribution by hydrometer analysis and Atterberg limits). Finally, during the third round, a Sand Sample from Mungu Maji sand quarry in the Singida region was submitted to the five laboratories, and they were requested to perform a particle size distribution test (i.e. wet method).

In order to limit the variability of the test results, it was necessary to ensure that each laboratory uses similar equipment and follows the same standard test method for each of the requested tests. For the clay samples, the laboratories were requested to determine particle size distribution in accordance with the British Standard (BS) 1377: 1990: Part 2: 9.5 (hydrometer analysis). In the case of the sand sample, particle size distribution was requested to be determined in accordance with BS 1377: 1990: Part 2: 9.3 (Wet method). For Atterberg limits, all the laboratories were requested to perform the tests in accordance with BS 1377: 1990: Part 2 (4.3 for liquid limit and 5.3 for plastic limit). It should be mentioned that the BS standard methods have also been adopted in the Central Material Laboratory (CML) testing manual that is widely used in Tanzania (MOW, 2000).

4 RESULTS AND DISCUSSIONS

4.1 Particle Size Distribution

Clay Sample 1 from a cement plant construction site in the Lindi region was first submitted to the selected five laboratories for testing (i.e. laboratories A to E). However, laboratory E did not perform the particle size distribution test, due to the unavailability of dispersive agent for hydrometer analysis. Figure 2 shows the particle size distribution results for Clay Sample 1 (i.e. percentage passing plotted against sieve size). From the results presented in Figure 2, it can be seen that the grading curves of all four laboratories compare fairly well for particle sizes larger than 0.063 mm. However, for particles smaller than 0.063 mm, there is variation of the grading curve, with laboratory D's result deviating significantly from those of the other laboratories. Furthermore, the results of laboratory D indicate discontinuity in the grading curve at 0.063 mm particle size. The 0.063 mm particle sieve is the transition between the wet sieving and the hydrometer analysis.

The particle size distribution results further indicate that all laboratories obtained fines content (materials smaller than 0.063 mm) ranging between 96% and 100%. The percentages of clay (material with size less than 0.002 mm) were 70%, 65%, 61% and 0% for laboratories A, B, C and D respectively. Silt content values (i.e. material with size larger than 0.002 mm but smaller than 0.06 mm) were 27%, 31%, 38% and 85% for laboratories A, B, C and D respectively. Sand contents (i.e. material with size larger than 0.06 mm but smaller than

2.0 mm) obtained were 3%, 4%, 1% and 15% for laboratories A, B, C and D respectively. These results suggest that the clay and silt content values obtained by laboratory D might be erroneous, as they differ significantly from the results obtained by the other laboratories.

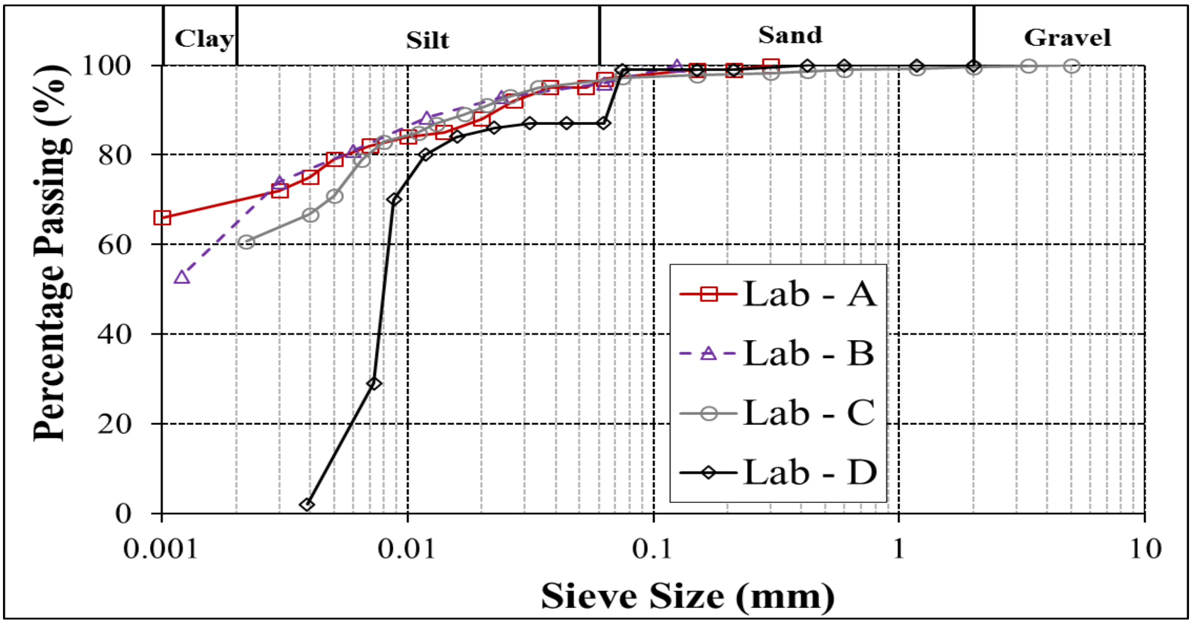

Figure 2: Particle size distribution results of Clay Sample 1 (from Lindi)

Following the assessment of the results of Clay Sample 1, another testing programme was designed to check consistency and verify the competency of the laboratories. Clay Sample 2 from Kitukutu in the Singida region was submitted to the same five laboratories for testing. During the second round of testing, laboratory A did not perform the particle size distribution test, due to unavailability of dispersive agent for hydrometer analysis. Furthermore, laboratory E performed the wet sieving only (i.e. without the hydrometer analysis). Figure 3 shows the particle size distribution results for Clay Sample 2. Similar to Clay Sample 1, the results presented in Figure 3 indicate that the grading curves of the four laboratories compare fairly well for particle sizes larger than 0.063 mm. However, for particles smaller than 0.063 mm, a significant variation of the grading curve was observed. The common problem of discontinuity in the grading curve at 0.063 mm can clearly be seen, which indicates that hydrometer analysis could be problematic to many civil and geotechnical engineering material testing laboratories in Tanzania.

The particle size distribution results further indicate that all laboratories obtained fines content (material smaller than 0.063 mm) ranging between 88% and 96%. The percentages for clay were 68% 67% and 58% for laboratories B, C and D, respectively; whereas silt contents obtained were 28%, 32%, and 31% for laboratories B, C and D respectively. All the laboratories found fairly comparable sand contents.

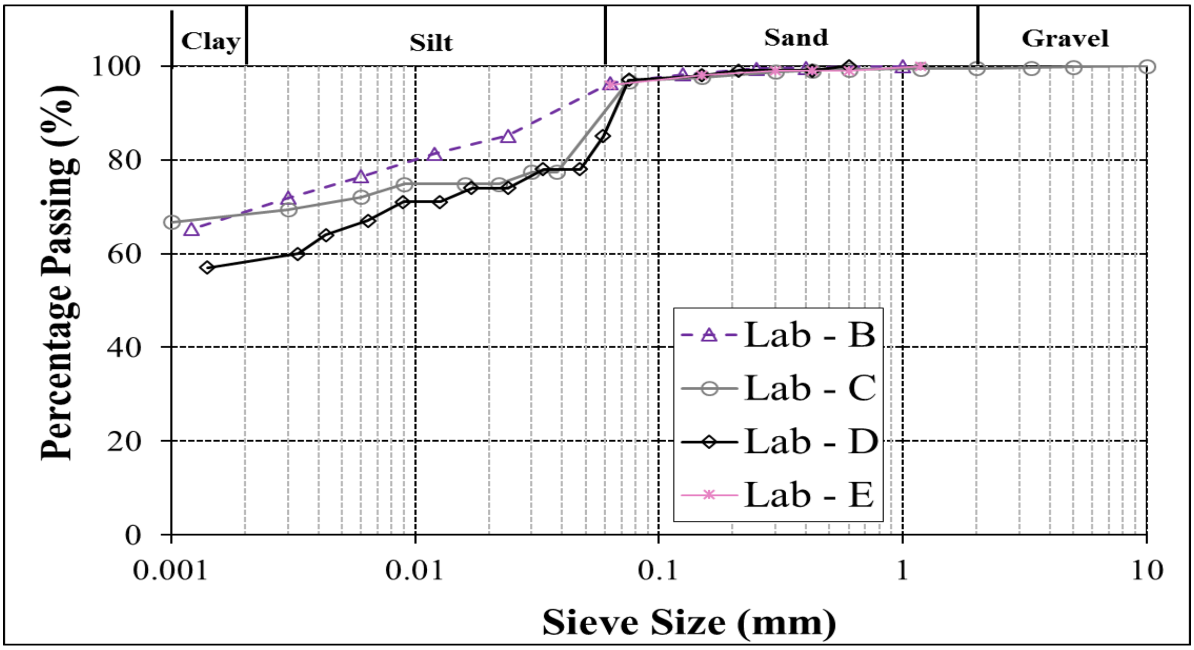

Figure 3: Particle size distribution results of Clay Sample 2 (from Kitukutu - Singida)

To further confirm whether hydrometer analysis was the only problem with respect to particle size distribution testing, a third round of testing was designed. During this round, a sand sample sourced from Mungu Maji quarry in the Singida region was submitted to the five laboratories for testing. Because it was sandy material, hydrometer analysis was not required during the third round of testing. Figure 4 shows the particle size distribution results for the sand sample. The grading curves of all five laboratories were similar, which indicates that all laboratories performed the particle size distribution test accurately. All the laboratories obtained fairly comparable fines, silt and sand contents.

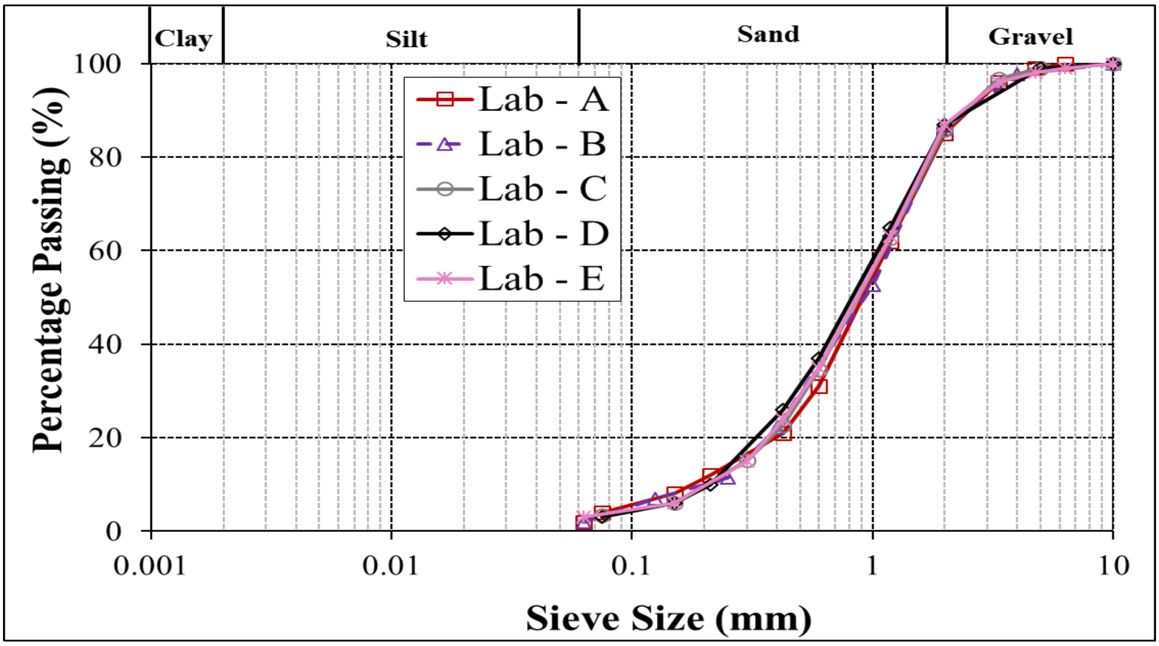

Figure 4: Particle size distribution results of sand sample (from Mungu Maji - Singida)

4.2 Atterberg Limits

The laboratories were next requested to determine Atterberg limits (i.e. liquid limit and plastic limit) during the first round of testing Clay Sample 1. The liquid limit, plastic limit and plasticity index results are presented in Figure 5. For the same material, a significant variation in respect of the Atterberg limits results can be observed. The liquid limit values ranged from 45% to 85%, with laboratory A's results being far lower than those of the rest of the laboratories. The plastic limit values ranged from 21% to 38%, whereas the plasticity index (i.e. difference between liquid limit and plastic limit) values ranged from 23% to 53%.

Figure 6 presents the results of Atterberg limits for Clay Sample 2, which were determined during the second round of testing (i.e. to check consistency and verify competency). The liquid limit values ranged from 51% to 118%, whereas the plastic limit values ranged from 14% to 54% and the plasticity index values ranged from 23% to 49%. Similar to the results of Clay Sample 1, the results yielded by laboratory A were generally lower than those found by the rest of the laboratories – which could be erroneous. The significant variation observed between the Atterberg limit results suggests that some of the selected laboratories were not able to determine these Atterberg limits accurately.

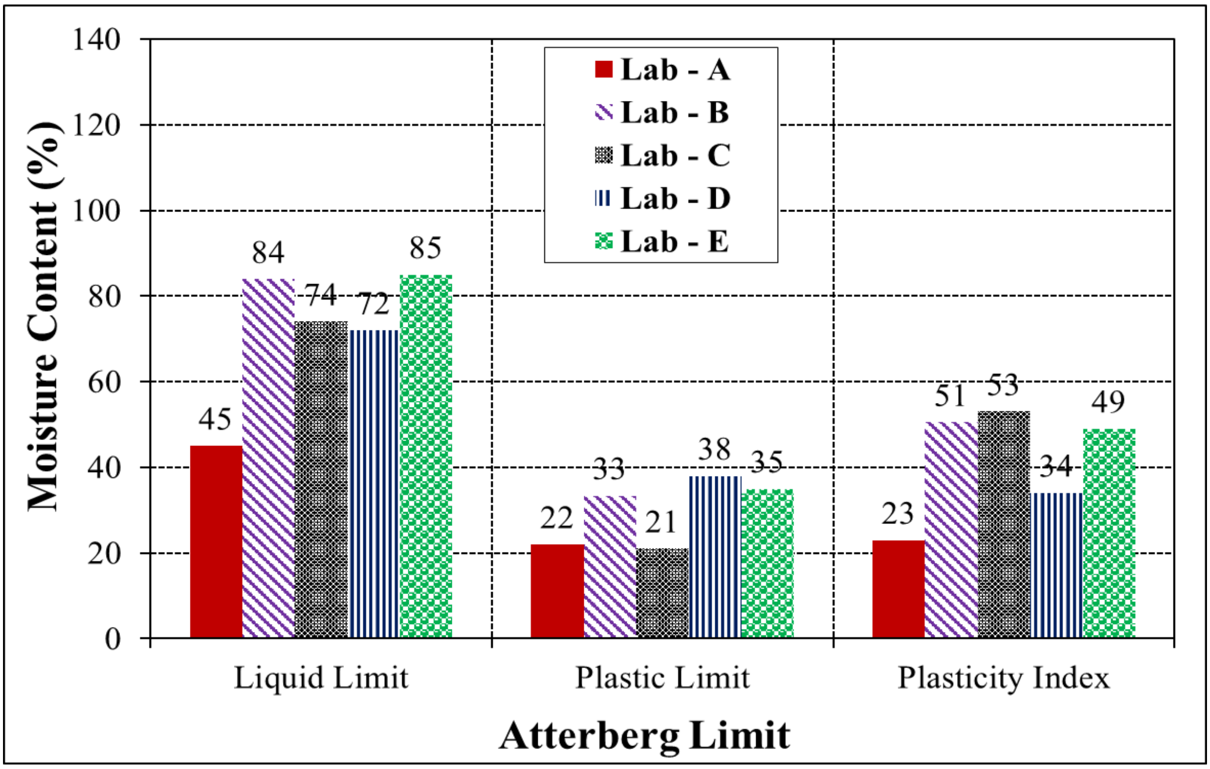

Figure 5: Atterberg limits – Clay Sample 1 (from Lindi)

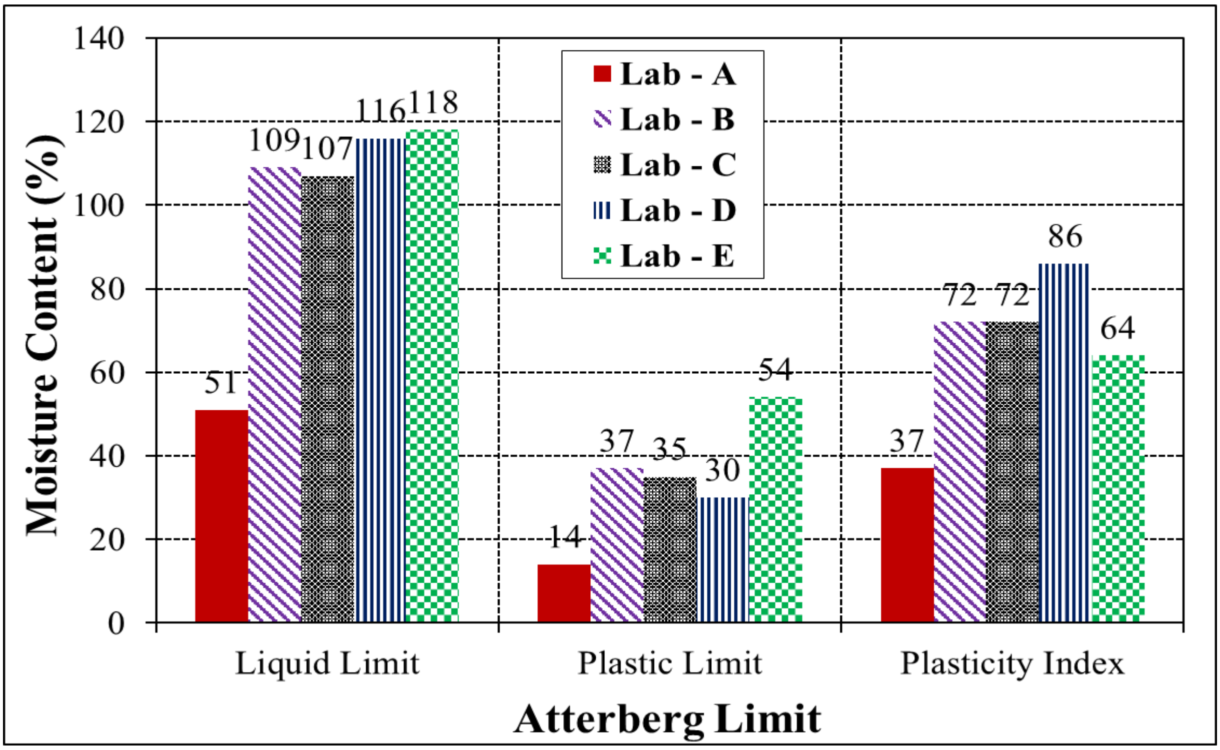

Figure 6: Atterberg limits – Clay Sample 2 (from Kitukutu - Singida)

4.3 Implications of the Test Results

The results of foundation indicator tests (i.e. the particle size distribution and Atterberg limits) are often used to classify soils, to assist in assessing the suitability of material to be used for construction, and to ascertain soil design parameters for foundations design. Therefore, accurate results are required to ensure correct soil classification. The test results presented in this paper have demonstrated that the same soil classified using British Soil Classification System (BSCS) is often classified differently by different laboratories. For Clay Sample 1, laboratories A classified the soil as CLAY of intermediate plasticity, while laboratories B and C classified the soil as CLAY of very high plasticity, whereas laboratory D found that the soil is SILT of very high plasticity. Laboratory E did not perform hydrometer analysis on Clay Sample 1, which made it impossible to classify the material. For Clay Sample 2, the classification by laboratories B, C and D indicated that the material is CLAY of extremely high plasticity, whereas laboratories A and E did not perform hydrometer analysis on Clay Sample 2 – hence soil classification was not possible.

According to Van der Merwe (1964), the heave to be expected under the building may be estimated based on the results of plasticity index and percentage of clay. One of the inputs in the formula is the swelling potential of expansive soil. For demonstration purposes, the relationship between the plasticity index and clay content of Sample 1 is used to classify the swelling potential of expansive soil, as proposed by William and Donaldson (1980). The relationship between the plasticity index and clay content of Clay Sample 1 is shown in Figure 7. From the plotted positions of Clay Sample 1, laboratories A and D classified the soil as having low swelling potential. In contrast, both laboratories B and C classified the sample as having the very high swelling potential of expansive soil. Laboratory E did not perform hydrometer analysis on Clay Sample 1 – hence the determination of the swelling potential was not possible.

The outcomes of the soil classification and swelling potential presented in this study demonstrate the importance of accurate test results. It is quite alarming to note that poor quality results from some of the laboratories may lead to the grossly inaccurate design of civil and geotechnical structures and result in wrongly rejecting or accepting materials for a particular work. Consequently, laboratory accreditation and proficiency testing should be encouraged to ensure that high quality results are obtained, and that the geotechnical fraternity is provided with reliable soil parameters.

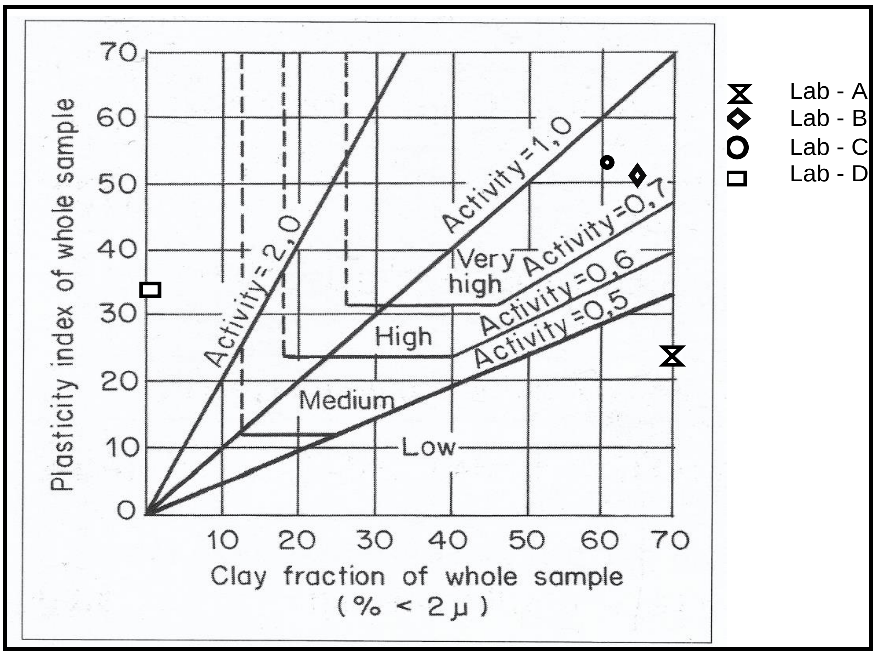

Figure 7: Swelling potential of Clay Sample 1

5 CONCLUSIONS AND RECOMMENDATIONS

This paper has presented an assessment of the quality of test results from five selected civil and geotechnical engineering material testing laboratories in Tanzania. Based on the results and discussions contained in this paper, the following conclusions and recommendations can be made:

- It is evident from the results that some of the selected laboratories were not able to determine the particle size distribution and the Atterberg limits accurately.
- Most of the laboratories were able to perform particle size distribution tests for particles larger than 0.063 mm. However, for particles smaller than 0.063 mm, which require hydrometer analysis, significant variations were observed in the test results obtained from the selected laboratories.
- The discontinuity in the grading curve at 0.063 mm appeared to pose a challenge for most of the selected laboratories, hence indicating that hydrometer analysis could be problematic to many civil and geotechnical engineering material testing laboratories in Tanzania.
- With respect to Atterberg limits, the results of laboratory A were generally lower than those of the other laboratories and appeared to be erroneous.
- To improve the quality of the results, there is a need to implement a formal laboratory accreditation system that complies with the relevant requirements of the International Organization for Standardization (ISO), of which the Tanzania Bureau of Standards (TBS) is a member body. In the meantime, laboratory registration bodies such as the Engineers Registration Board (ERB), should consider implementing compulsory

proficiency testing programme for civil and geotechnical engineering material testing laboratories.

- All civil and geotechnical engineering material testing laboratories should be encouraged to participate in the proficiency testing programmes, and they should consider it as an opportunity to improve the quality of their results, rather than as a finger-pointing exercise.
- It is recommended that the assessments presented in this paper should be extended to cover not only a wide range of laboratories, but also other material properties.

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REFERENCES

[1] Grieve, G.R.H. 2002. Inter-laboratory proficiency evaluations between several Gauteng-based concrete and aggregate testing laboratories. Journal of the South African Institution of Civil Engineers. Vol. 44, No. 1, pp 31-34.

[2] ISO 17025. 2010. General requirements for the competence of testing and calibration laboratories. Geneva, Switzerland.

[3] ISO 17043. 2010. Conformity assessment – General requirements for proficiency testing. Geneva, Switzerland.

[4] Jacobsz, S.W. and Day, P. 2008. Are we getting what we pay for from geotechnical laboratories? SAICE Magazine. April 2008, Vol. 16, No. 4, pp 8-11.

[5] MOW. 2000. Laboratory Testing Manual. Ministry of Works. Dar es Salaam, Tanzania.

[6] Nielsen, H.S. 2002. Can proficiency testing add value? 2002 NCSL International Workshop and Symposium. San Diego, USA.

[7] Nielsen, H.S. 2003. Determining Consensus Values in Inter-laboratory Comparisons and Proficiency Testing. 2003 NCSL International Workshop and Symposium. San Diego, USA.

[8] Nielsen, H.S. 2004. Experience Gained from Offering Accredited 3rd Party Proficiency Testing. 2004 NCSL International Workshop and Symposium. San Diego, USA.

[9] SANS 17025. 2010. General requirements for the competence of testing and calibration laboratories. Pretoria, South Africa.

[10] SANS 17043. 2010. Conformity assessment – General requirements for proficiency testing. Pretoria, South Africa.

[11] Softic, A., Uzunovic, N.Z. and Basic, H. 2012. Proficiency testing and interlaboratory comparison in laboratory for dimensional measurements. Journal of Trends in the Development of Machinery and Associated Technology. Vol. 16, No. 1; pp 115-118.

[12] Van der Merwe, D.H. 1964. The prediction of heave from the plastic index and percentage clay fraction of soils. Journal of the Geotechnical Division of the South African Institution of Civil Engineers. Vol. 6, No. 6.

[13] Williams, A.A.B. and Donaldson, G.W. 1980. Building on expansive soils in South Africa. Proceedings of the 4th International Conference on Expansive Soils. ASCE Publication, Vol. 2.