

Permeability characteristics of volcanic ash soil in Papua New Guinea

B. Panga BE, GSPE (PNG)
Department of Works, Lae, P.N.G

ABSTRACT: Volcanic ash soils have been encountered in the Highlands Region of Papua New Guinea during road construction. Considerable difficulties have been encountered due to the unusual characteristics of these volcanic ash soils. Basic classification tests were undertaken to determine the material properties of the prepared sample. Samples were prepared in three moisture conditions; natural, air-dried and oven-dried. Two test methods were used for determining permeability of the material, the Falling Head Permeameter test and One Dimension Consolidation Test. The latter was used as an alternative test method. From this investigation it was concluded that following drying, volcanic ash soil experienced decreases in plasticity, variation in particle size and increases in permeability characteristics. Suggested recommendations for the use of volcanic ash soils are outlined based on test results. A number of studies done on the unusual characteristics of other volcanic derived soils have also been evaluated as providing background material for the understanding of this study.

1. INTRODUCTION

Volcanic ash soils have been commonly encountered during the construction of roads in the Highlands Region of Papua New Guinea. These soils have been far from ideal as a construction material and considerable difficulties have been encountered when these materials have been used in pavement and embankment construction. The volcanic ash is believed to have originated from two extinct volcanoes, Mt. Giluwe and Mt. Ialibu located between Mt. Hagen and Mendi. Figure 1 shows approximate locations where volcanic ash soils are found in Papua New Guinea. The difficulties encountered are associated with sensitivity of the soil to moisture content during field compaction.

In this investigation of the permeability characteristics of volcanic ash soil, variations in the coefficient of permeability and the physical properties of the soil will be examined when subjected to varying drying processes. Permeability tests were undertaken using material prepared at three moisture conditions; natural, air-dried and oven-dried. Natural condition was such that the sample was moist "as received" from the roadwork project, a cutting near Mendi, in Southern Highlands Province. Air-dried condition was such that the sample was air-dried in the sun for six to eight hours. An oven-dried sample was such that the sample was oven-dried in a high temperature oven (105-110°C) for maximum of twelve hours.

Basic classification tests were used to identify the properties of the material prepared under the three moisture conditions. Investigation also looked at a number of studies undertaken on the unusual characteristics of volcanic derived soils, these being outlined in the literature review.

2. LITERATURE REVIEW

Available literature indicates that the general characteristics of volcanic ash soils are governed by the minerals present within the soil medium. In this literature

review the mineral content, plasticity characteristics and permeability characteristics are presented. This will establish a frame work against which the experimental results will be reviewed.

Research (Moore and Styles, 1988) observed that volcanic ash soils were found to be amorphous to x-ray diffraction, meaning that the sub-particles have no fixed form or shape. It was concluded that the mineral present was probably allophone, which is a clay mineral found in volcanic ash soils.

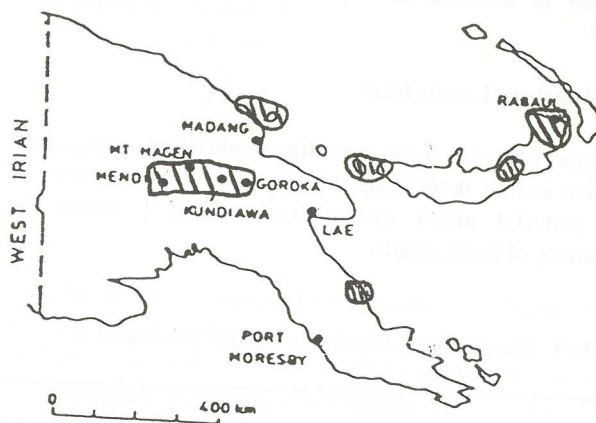


Figure 1. Map of Papua New Guinea showing approximate locations of volcanic ash soils.

Fieldes (1966) and Fieldes and Furkert (1966) described the allophones as, when no drying out of volcanic soil has occurred allophone minerals consist of gel-like fragments of random alumina-silicate held together by random links at a relatively small number of points. A great deal of water is enclosed in the very open structure. When drying occurs the removal of water causes the structure to shrink and the number of linkage points between the fragments steadily increases, leading eventually to the formation of hard grains.

Quinouse (1963) indicated that the process of air drying reduces this type of soils to almost non-plastic behaviour

with a plasticity index as low as 6.0 percent. The United State Department of Interior, Bureau of Reclamation (1968) states that permeability in some soils is very sensitive to small changes in density, water content, and gradation. A few percentage points variation in any one of these factors may result in substantial changes in permeability.

Discussions with Mr. Graham Hancock, of the Department of Mining Engineering, Papua New Guinea University of Technology, indicated that when volcanoes erupt they give out ashes which are actually fine fragmented glass particles. These fragmented glasses, through weathering, form primarily into allophone. Through weathering and chemical reaction allophone forms halloysite, then illite and finally kaolinite. It was discussed that the plasticity index of the soil decreases as clay minerals change from allophone to kaolinite.

3. LABORATORY INVESTIGATION

Permeability tests on the subject material were carried out using the Falling Head Permeameter, with the one-dimensional consolidation test utilised as an alternative testing method. Basic classification tests to determine material properties included Atterberg limits tests and particle size analysis tests including hydrometer tests for fines less than 75 microns in size. A standard compaction test was undertaken on the natural condition material to establish the optimum moisture content. All tests were carried in accordance with Australian Standard - AS 1289.

3.1 Atterberg Limits tests

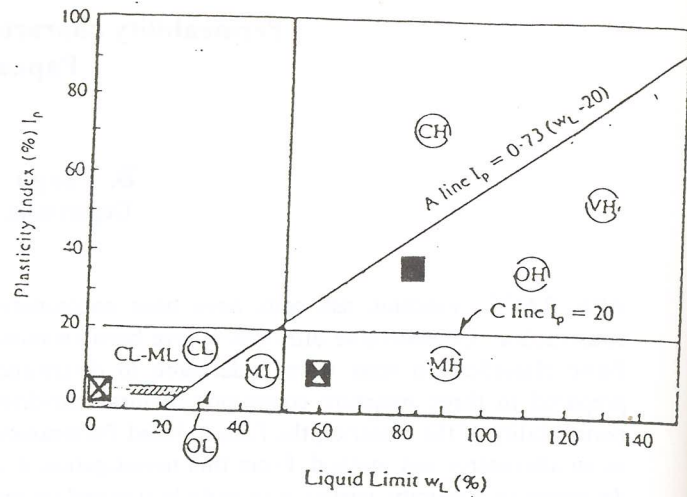
Atterberg Limits tests and linear shrinkage tests were carried out to determine the plasticity characteristics of the material under investigation. Table 1 shows the summary of these results.

Table 1: Summary of Atterberg Limits Test Results

	Natural Condition	Air-dried condition	Oven-dried Condition
Liquid Limit (%)	84	59	48
Plastic Limit (%)	49	50	50*
Plasticity Index (%)	35	9	0
Linear Shrinkage (%)	11	5	0.5

* Result likely to be slightly less than 50. Experimental uncertainty due to difficulty in thread rolling.

Table 1 shows that liquid limits and plasticity indices decreased following drying processes. Like Quinous (1963), Table 1 shows that processes of drying reduces the soil to almost non-plastic behaviour. Soils may be grouped according to their liquid limits and plasticity indices on a plasticity chart as shown in Figure 2.



- = natural condition
- ⊗ = air-dried condition
- ⊙ = oven-dried condition

Figure 2. Summary of Plasticity Test Results

It can be deduced from this figure that the soil appears to have been modified from a CH material to an MH or ML following drying. However, this is not possible physically without irreversible changes in the mineralogy of the soil when subjected to the various drying processes.

3.2 Particle size analysis

Atterberg Limits tests have indicated changes in the mineralogy of the soil that may be visualised by the gradation curves for the varying drying conditions. Particle size analysis tests carried out by wet sieving and hydrometer tests were performed for fines determinations less than 75 microns. In accordance with AS 1289, C6.3 - 1977, hydrometer testing of the oven-dried sample was not relevant due to less than 10% fine of the material passing 75 micrometer sieve.

Figure 3 presents the summary of particle size distribution test results showing graphs A, B and C for natural, air-dried and oven-dried samples respectively.

It is apparent from Figure 3 that particle sizes have increased following drying, and especially oven-drying. Like Fieldes and Furkert, (1966), Figure 3 demonstrates the change in the grain particles of volcanic ash soil when subjected to varying drying processes, that is, the formation of harder, more discrete particle with increased drying.

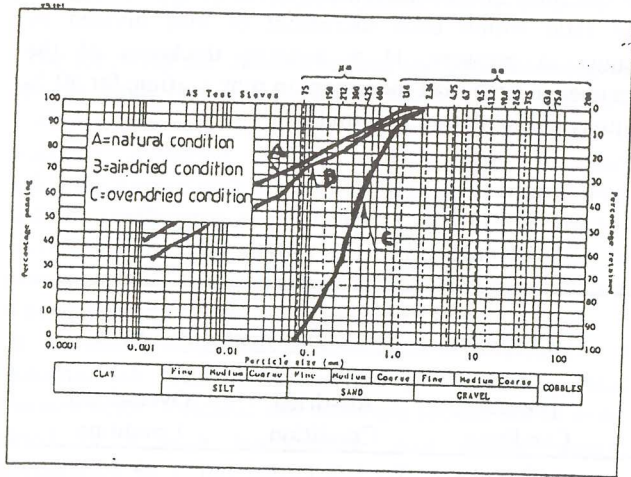


Figure 3. Summary of particle size analysis tests.

Table 2. Summary of test results using Falling Head Permeameter

Moisture Condition	Number of Tests	Coefficient of Permeability (k) x 10 ⁻⁹ m/s			
		Minimum	Mean	Maximum	Standard Deviation
Natural	3	1.742	1.905	2.273	0.32
Air-dried	10	660.6	806	1181	145.0
Oven-dried	10	195	204	217	9.0

3.4.1 Falling Head Permeameter tests.

The coefficient of permeability was determined on the material at Optimum Moisture Content using the Falling Head Permeameter.

During the preparation of the test samples, the natural and air-dried samples were soaked over night before being tested, while oven-dried samples were soaked for two weeks before testing. This was done to achieve saturation. Equation (1) was used to compute the coefficient of permeability for the Falling Head Permeameter tests.

$$k = 2.84al \frac{\log H_1 - \log H_2}{t_1 - t_2} \times 10^{-5} \quad \dots(1)$$

where k= coefficient of permeability; A= cross section area of the stand-pipe; H₁ = initial height of the water level; H₂ = final height of the water level; t₁ = initial time in seconds; t₂ = final time in seconds; L = length of the sample. All dimensions are in millimetres (mm).

Table 2 presents a summary of results obtained from the

3.3 Standard compaction test

A standard compaction test was undertaken on the material at natural moisture condition to establish the optimum moisture content, the chosen condition at which the test samples were to be compacted for the permeability tests. From this test the established Standard maximum Dry Density was 1.265 t/m³ and Optimum Moisture Content was 35.0%. (AS 1289.E.1.1)

3.4 Permeability characteristics

The United States Department of Interior, Bureau of Reclamation (1968) demonstrated that permeability in some soils is very sensitive to small changes in density, water content and gradation. Permeability tests on the volcanic ash soil may verify the changes in the properties of the soil as shown by the Atterberg Limits and particle size analysis tests.

Falling Head Permeameter Tests. From this Table it shows that with a coefficient of permeability at 10⁻⁹ m/s, the volcanic ash soil tested is a relatively impermeable soil. Considering the mean values factored by 10⁻⁹, it can be seen that the coefficient of permeability increased dramatically following drying. The results of air-dried and oven-dried samples do not reflect the grading curves as shown in Figure 2. These indicated the differences in degree of saturation during the preparation of the samples.

3.5 One dimensional consolidation tests

A one-dimensional consolidation test was carried out to assess this method as an alternative test to determine permeability characteristics of volcanic ash soils. The summary of the result is presented as Table 3. Equation (2) was used to compute the coefficient of permeability.

$$k = 9.81 \frac{C_v A_v}{1 + e} \quad \dots(2)$$

$$C_v = \frac{0.1116H^2}{t_{90}} \quad \dots(3)$$

Where k = coefficient of permeability; C_v = coefficient of consolidation as given by equation (3); e = void ratio of

the specimen at each increment of load; A_v = change in void ratio within each increment of load divided by change in pressure, H = average thickness of the specimen at each load increment in mm; t_{90} time for 90 % primary consolidation in minutes.

Table 3. Summary of Consolidation test results

Applied Pressure (kPa)	Change in Void Ratio			Coefficient of Permeability (k) $\times 10^{-9}$ m ² /s		
	Natural Condition	Air-dried Condition	Oven-dried Condition	Natural Condition	Air-dried Condition	Oven-dried Condition
25	0.0005	0.005	0.003	0.4	0.1	4.1
50	0.0008	0.004	0.011	0.3	0.4	10.5
100	0.015	0.009	0.013	0.5	0.5	10.1
200	0.027	0.013	0.020	0.7	0.4	6.0
400	0.037	0.028	0.028	0.4	0.4	2.2
800	0.075	0.08	0.035	0.5	0.9	2.8
1600	0.119	0.105	0.047	0.4	0.7	1.7

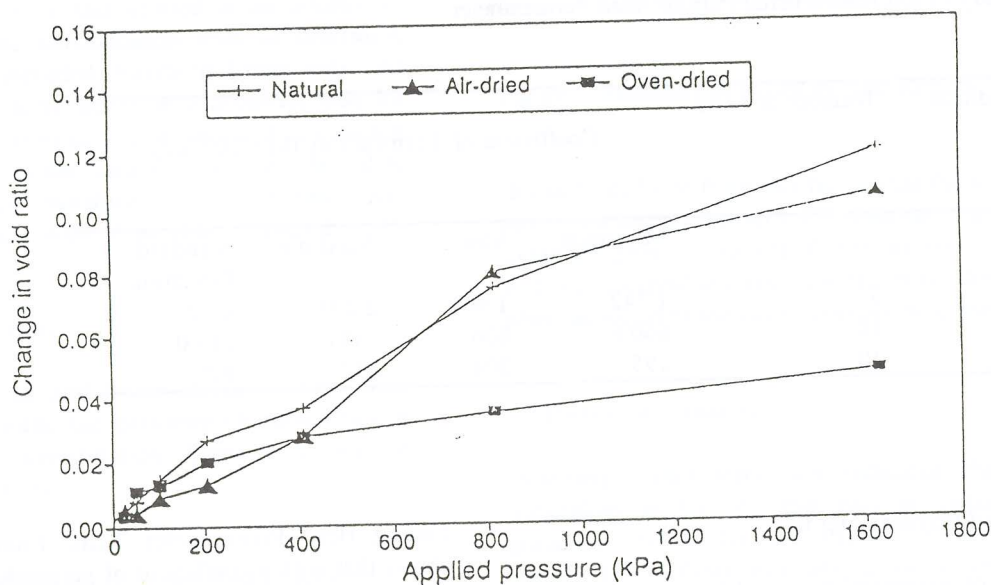


Figure 4. Void ratio versus applied pressure

There are two alternative methods for determining coefficient of consolidation. These are from the square root time and log time methods. The former is preferred in sandy, silty soils, thus this method was used for this investigation because the grading curves indicated a considerable amount of silt in its natural condition. From this method the time for 90% primary consolidation (t_{90}) was obtained to compute the value of C_v .

Table 3 shows an increase in coefficient of permeability when comparing the oven-dried sample to the natural and air-dried samples. Figure 4 was plotted from Table 3 showing the change in void ratio against applied pressure. It can be generalised from Figure 4 that for the same pressure applied, natural and air-dried condition samples yielded greater changes in void ratio than the oven-dried sample. However, this is only applicable for applied

stresses greater than 400 kPa. For this level of investigation it is unpredictable for the behaviour of the soils at the applied stresses less than 400 kPa.

Figure 4 indicates how a small change in void ratio for the oven-dried condition samples can yield a greater coefficient of permeability. This indicates, that the change in the mineralogy of the soil when subjected to varying drying processes have affected the permeability characteristics of a volcanic ash soil. Figure 4 also indicates substantial variations in the change of void ratio at elevated pressures. The materials not subjected to oven-drying appear to undergo greater compression than that oven-dried. This appears to support the grading variations and the work of Fieldes (1966) who indicated the formation of harder grains upon drying.

4. CONCLUSIONS AND RECOMMENDATIONS

The following are the conclusions and recommendations derived from this investigation into Volcanic ash soil. Volcanic ash soil, as tested, experienced decreases in plasticity following drying; particle sizes increased following drying with marked changes upon oven-drying, and the coefficients of permeability of volcanic ash soil increased following drying out. The changes may be associated with the changes in the mineralogy of the soil when subjected to varying drying processes.

It is recommended that determination of permeability of volcanic ash soils be by the use of the Falling Head Permeameter. Volcanic ash materials should not be oven-dried in a high temperature oven during sample preparation as it has substantial effects on the material properties. During field compaction of this type of soils it is recommended that disturbance of the materials be minimised. With respect to this, static rolling techniques would appear to be superior to processes that are associated with machinery likely to "pulverise" the material during compaction. Indeed multi-tyred rollers have proven satisfactory with these materials in the PNG environment.

REFERENCES

- Australian Road Research Board Volume 2: Part 2 (1964). "Classification of Volcanic Soils for Roadmaking".
- Fieldes, (1966) and Fieldes & Furkert (1966). Published by A.A Bachema/Rotterdam (1988) "Tropical Soils of Nigeria in Engineering Practice".
- Lee. Ian. K et al (1983) "Geotechnic Engineering"
- Moore. P. J. & Styles. J. R. (1988) University of Melbourne, Australia "Some Characteristics of A Volcanic Ash.
- Quinones P. J. (1963) "Compaction Characteristics of Tropically Weathered Soils" Published by UNIVERSITY MICROFILMS
- United States Department of the Interior Bureau of Reclamation "Earth Manual" First edition - Revised, Second printing Denver, Colorado (1968)
- Standards Australia "Australian Standard, AS 1289, Testing of Soils for Engineering Purposes".