Geotechnical Characterization of Weathered Limestone used as an Alternative Embankment Material for Roadway Construction

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Abstract: Weathered limestone locally called "*Anapog*" is abundantly available in Visayan region such as Cebu. This study was undertaken to provide geotechnical characterization of *Anapog* so that it can be safely and efficiently utilized as an alternative construction material. Physical properties, compaction behavior, shear strength properties, consolidation properties and load bearing capacity of *Anapog* from Consolacion, Cebu were determined through series of ASTM standard tests. Its microfabric structure and chemical composition were determined from Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) test. *Anapog* consists of sub-angular platy particles with chemical elements of Carbon, Oxygen, Aluminum, Silicon, Calcium, and Iron. Compaction behavior from Proctor test is rated as fair to excellent when used as embankment material. Consolidation properties obtained from the consolidation test indicate that *Anapog* is slightly compressible when it is normally consolidated and very slightly compressible when it is overconsolidated. Shear strength properties obtained from the direct shear test showed a ductile stress-strain behavior both in dry and saturated condition. Values of friction angle ranges from 30^o to 32^o. Based from load bearing capacity test, pure *Anapog* can be utilized as a subgrade in road construction. It can also be utilized as subbase and base course when blended with a minimum of 30% to 40% crushed stone and gravel. High values of friction angles, excellent compaction behavior, low compressibility, and adequate load bearing capacity manifested by weathered limestone in this study are indications that it is suitable as an alternative material for roadway construction and other engineering applications.

Key Words: *Anapog*; physical properties; compaction behavior; consolidation properties; shear strength; load bearing

1. INTRODUCTION

The soil composition of island of Cebu consists mainly of limestone dispersed over bedrock formation. The weathering and erosion of this soil formation produced *Anapog*. *Anapog* is abundantly found in the municipality of Consolacion, one of the four cities that constitute Cebu Metropolitan Area. The directives of Dept. of Public Works and Highways (DPWH) Executive Order 95, Series of 1991 allow the use of this locally available weathered limestone *Anapog* as base course for road construction so as not to delay the road construction projects arising from scarcity or non-availability of the conventional base course materials. Preliminary study was conducted by DPWH specifically for *Anapog* found in Bohol which is a nearby province of Cebu. However, the preliminary study conducted by DPWH on the said material is not extensive enough and certain geotechnical properties of *Anapog* like shear strength and consolidation behavior are still unknown. Its behavior may then be unpredictable when used in various engineering applications and may lead to its inefficient utilization.

This study was undertaken to establish the geotechnical properties of *Anapog* found in Consolacion, Cebu and evaluate its potential use as an alternative material for road construction and other engineering applications. This study specifically aims to determine the physical properties, microfabric structure, compaction behavior, load bearing capacity, consolidation behaviour, and shear strength of *Anapog*. It is also the aim of this study to determine the optimum mix proportion of *Anapog* and crushed stones that will satisfy the criteria set forth by DPWH for materials used in roadway construction.

The characterization of *Anapog* in this study will serve as guide to fully understand the behavior of *Anapog* when it is use for engineering application. The parameters determined guarantees *Anapog's* efficiency as a construction material. Thus, using it as an alternative construction material would help in preventing the depletion of the natural resources currently being used in the construction industry. Having a locally available material that may be used for construction will contribute to the economic development and infrastructure growth in the region.

Many varieties of limestone deposits are formed all around the world because of the diversity in environmental conditions. These types of limestone may vary in terms of behavior and geotechnical properties. Studies about the geotechnical properties of various limestone types were conducted (Ifelola and Afu, 2014; Fourniadis, 2010) and the results proved that limestone has strength properties suitable for engineering purposes such as roadway embankment.

The principal structural component of the pavement is the road base. It is responsible for distributing the load from the surface to the sub-base and subgrade so as to not exceed the strength of the layers (Siswosoebrotho et al, 2005). And since the base course has the duty to distribute the load, it must have a high stiffness and strength to resist the high pressure due to the loads imposed upon them. The most important material for the construction of the base course layer is the aggregate which have certain characteristics that help enhance the quality of the road base course (Johannessen, 2008). Aggregates for base course consist of hard, durable particles or fragments of crushed stone, crushed slag, crushed or natural gravel and filler of natural or crushed sand, or other finely divided mineral matter. For some places where the typical base course is limited, the mixture of weathered limestone and crushed stones or gravel can be used as long as the mixture meets the requirements for aggregate base course given by Item 201 of DPWH Bluebook (DPWH, 2013). The suggested mixture was 40% weathered limestone and 60% crushed stones.

2. METHODOLOGY

2.1 Source of Anapog Sample

The *Anapog* sample used in the experimentation was acquired from limestone quarries in Consolacion Cebu. The wet *Anapog* is yellowish in color and has the tendency to clumps when mixed with water. Dried *Anapog* has paler hue of yellow, closer to dirty white colour and easily disintegrate into finer particles.

2.2 Test Program

Pure *Anapog* was subjected to series of ASTM Standard Tests to determine its physical and mechanical properties. A scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX) was also performed to determine the its microfabric structure and chemical composition. The laboratory tests and corresponding ASTM standards are summarized in Table 1.

Table 1 Test program of Pure *Anapog*

Test Program	ASTM Standards
Determination of Physical Properties	
Specific Gravity	ASTM D854
Atterber Limits	ASTM D4318
Grain-Size Analysis	ASTM D6913
Index Density Test	ASTM D4253/ ASTM D4254
SEM-EDX	
Determination of Mechanical Properties	
Proctor Test	ASTM D698
One-dimensional Consolidation Test	ASTM D2435
Direct Shear Test	ASTM D3080
California Bearing Ratio Test	ASTM D1883

The compaction behaviour of pure *Anapog* was evaluated from test results of Proctor test. Through this test, the optimum moisture content at which the compaction process will give the maximum weight per volume of sample was determined. Consolidation properties to describe and predict the compressibility of pure *Anapog* was determined through one-dimensional consolidation test. Direct shear test was performed to determine the shear strength properties of the pure *Anapog*. The test was conducted with samples in dry and saturated condition with initial relative density of 90%. It was subjected to varying vertical stresses of 54.5 kPa, 109 kPa, and 218 kPa simulating the expected loading conditions when the material will be used as road base.

To determine the load bearing capacity of *Anapog* and to evaluate its potential for roadway construction, the California Bearing Ratio (CBR) Test was performed. The test was done on pure and blended *Anapog* in various mix proportion with crushed stones as shown in Table 2. The compacted sample was subjected to penetration test after it was soaked in water for 24-hrs. to simulate the condition in the field where road base are fully saturated.

Table 2. Mix proportion of pure and blended *Anapog* for the CBR test

Designation	Mix Proportion (% by volume)	
	Crushed Stones	*Anapog*
Pure Anapog		100%
60C40A	60%	40%
40C60A	40%	60%
30C70A	30%	40%

3. RESULTS AND DISCUSSION

3.1 Microfabric Structure and Chemical Composition

The micrograph of *Anapog* is shown in Fig. 1. The microfabric structure suggests that *Anapog* is generally comprised of sub-angular, platy, clay-size particles with minimum voids in between soil particles. The chemical composition of *Anapog* are Carbon (C), Oxygen (O), Aluminum (Al), Silicon (Si), Calcium (Ca), and Iron (Fe). The presence of Silicon and Aluminum indicates that there is a presence of clay in the sample since the principal elements in clay are silicon, aluminum and oxygen. Limestone primarily composed of calcium and carbon blended with clayey soil results to an improved consolidation properties and shear strength properties particularly on its angle of friction and cohesion (El-Shourgaby et al, 2004).

3.2 Physical Properties

The grain-size distribution of *Anapog* consists of 74% fines, 11% fine sands and 15% medium sands. The average diameter that represents the sample, D_{50} is approximately 0.055 mm. Its grain-size distribution curve appears to be poorly graded. According to Unified Soil Classification System (USCS), *Anapog* is classified as silty clay with sand having the symbol CL-ML. From AASHTO soil classification system, *Anapog* is classified as silty soil with group index of 1 under the category of A-4. This indicates that its performance as subgrade is good to fair. The soil constants that represent the physical properties of *Anapog* are shown in Table 3. The plasticity index is low, this suggests that *Anapog* is slightly plastic.

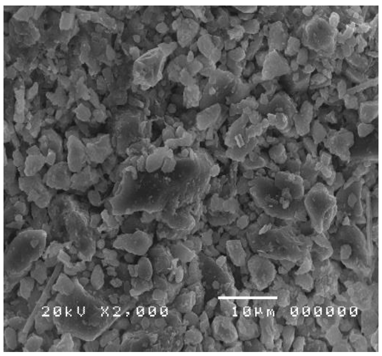

Fig. 1 Micrograph of Anapof at 2000x magnification

Table 3. Soil constants of *Anapog*

Soil Constant	Value
Specific Property	2.58
Liquid Limit, LL (%)	21
Plastic Limit, PL (%)	17
Plasticity Index, PI (%)	4
Minimum Void Ratio	0.742
Maximum Void Ratio	1.15
Maximum Dry Unit Weight (kN/m^3)	14.53
Minimum Dry Unit Weight (kN/m^3)	11.77

3.3 Compaction Behavior

From Proctor test, the maximum dry unit weight of *Anapog* is 17.25 kN/m^3 with optimum moisture content of 14.72%. Its anticipated embankment performance under the AASHTO classification is rated as fair to excellent. Under the USCS standards, its compaction characteristics is rated as good to fair; its value as subgrade material is good to fair; its value as base course is fair to poor; and its value as embankment material is reasonably stable when dense.

3.4 Consolidation Properties

The consolidation parameters such as the preconsolidation pressure, compression index (Cc) and recompression index (Cr) were determined from one-dimensional consolidation test. These consolidation parameters are needed to determine the consolidation settlement of *Anapog* when subjected to vertical pressure. The compression and recompression ratios were calculated to determine the classification of *Anapog* in terms of compressibility based from the classification criteria of Coduto (1999). The consolidation parameters are shown in Table 4. Based from test results, *Anapog* may be classified as slightly compressible when it is normally consolidated and very slightly compressible when it is overconsolidated.

Table 4. Consolidation parameters and compressibility of *Anapog*

Consolidation Parameters	**Value**	
Preconsolidation pressure (KPa)	140	
Compression index, Cc	0.1122	
Recompression index, Cr	0.0123	
Compressibility Ratios	**Value**	**Classification**
Compression ratio, $\frac{C_c}{1+e_o}$	0.06923	Slightly compressible
Recompression ratio, $\frac{C_r}{1+e_o}$	0.0069	Very slightly compressible

3.5 Shear Strength Properties

To properly evaluate the suitability of *Anapog* in other engineering applications such as embankments or structural fills, it is important to determine its shear strength properties. Samples in dry condition were subjected to strain rate of 1.25mm/min. to simulate rapid loading. Figure 1 (a) shows the stress strain diagram of *Anapog* in dry condition. Higher shear stress values were obtained for higher values of overburden pressure. The samples were able to sustain constant values of shear stress as it reached the critical state, indicating that the sample experienced failure in a ductile manner. Figure 1 (b) shows that the volumetric change behavior of the sample is purely compressive. For every overburden pressure, the volumetric strain continuously increases until the end of the test. This could be an effect of the sub-angular, finer particles that comprises *Anapog* wherein particles can easily fill-in the void spaces.

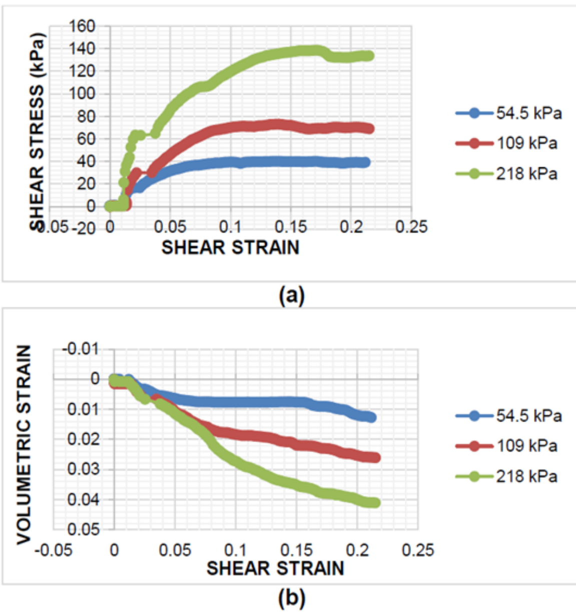

Fig. 1. Shear stress against shear strain (a) and volumetric strain against shear strain (b) of *Anapog* in dry condition

The stress-strain and volumetric strain behavior of saturated *Anapog* in drained condition are shown in Fig. 2 (a) and (b). The drained condition was achieved by allowing the sample to consolidate before applying the shearing force at a slow strain rate of 0.12 mm/min. The saturated samples exhibited a ductile failure similar to samples in dry condition. A rapid increase in volumetric strain can be observed at early stage of test. Values of compressive volumetric strain were higher as compared to values in dry condition. This is because of the presence of water in the void spaces that serves as lubricant to facilitate to re-arrangement of particles into denser configuration.

The ductile behavior manifested by *Anapog* is preferable as this will not lead to progressive collapse. Many of the design procedure in geotechnical engineering assume that the soil can be relied on to behave in a ductile manner, where it will undergo continued deformation at constant load. This is in contrast to a brittle material, which at failure, breaks and loses it load carrying capacity entirely. The angle of friction of *Anapog* is in the range of 30^o to 32^o with cohesion value of 1.08 KPa to 7.92 KPa.

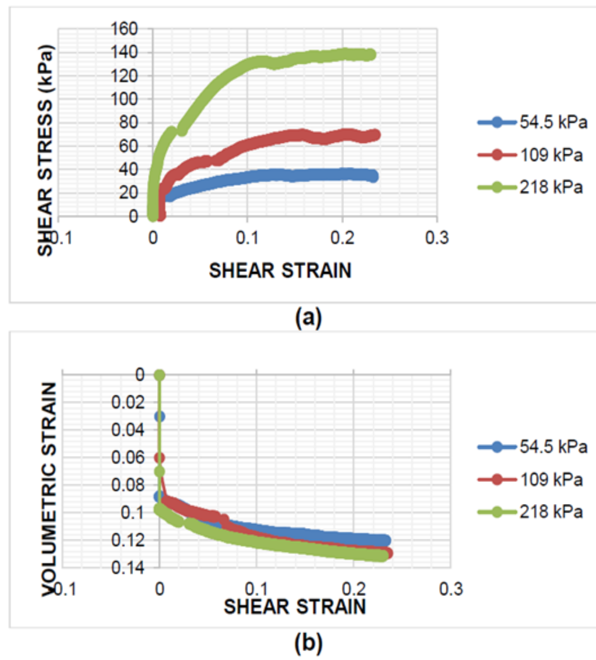

Fig. 2. Shear stress against shear strain (a) and volumetric strain against shear strain (b) of Anapog in saturated condition

3.6 Load Bearing Capacity

The California Bearing Ratio (CBR) test was performed to determine the load bearing capacity of *Anapog* in different mix proportion with crushed stones. The CBR test is essentially a penetration test which determines the suitability of a certain material in road construction. The purpose of this test is to determine the resistance of the material to heavy loads often induced by vehicles. Results of the CBR test would determine the thickness of the pavement as well as its corresponding economic impact. Table 5 shows the CBR index values of *Anapog* in different mixtures, its corresponding ratings for roads and runways, and its uses based from the Soil Ratings for Roads and Runways (Bowles, 1978).

Table 5 CBR Values of *Anapog*

	CBR Value	General Rating	Use
Pure Anapog	5	Poor to Fair	Subgrade
60C40A	82	Excellent	Base
40C60A	40	Good	Base and Subbase
30C70A	24	Good	Base and Subbase

It is a requirement stated in Item 201 of DPWH Bluebook (DPWH, 2013) that the soil must have a minimum CBR index value of 80 at maximum dry density for it to be qualified as a base course material. Based on the results of the experiment, only mixture 60C40A satisfies the requirement of DPWH. Though mixture 40C60A and mixture 30C70A may also be used as a base course according to the criteria of Soil Ratings for Roads and Runways, it is not ideal to adapt these blends as it did not reach the minimum CBR index value requirement of DPWH. The results from this study indicate that the *Anapog* from Consolacion, Cebu may be used as a base course as long it is combined with 60% crushed stones.

4. CONCLUSIONS

Geotechnical characterization of *Anapog* from Consolacion, Cebu was undertaken to evaluate its applicability as embankment material. Based from the series of experiments conducted, the following results were obtained:

Anapog consists mostly of fine particles with an average diameter of 0.055 mm. It is poorly graded classified as silty clay with sand. Its microfabric structure is composed of sub-angular platy, clay-size particles with minimum inter-granular voids.

Compaction behavior showed that *Anapog* is suitable as an embankment material having a rating of fair to excellent, with compaction characteristics of good to fair as subgrade material and fair to poor as base course.

Consolidation properties describe *Anapog* as slightly compressible when it is normally consolidated and very slightly compressible when it is overconsolidated.

The stress-strain behavior of *Anapog* both in dry and saturated conditions manifested a ductile failure with compressive volumetric strain. The angle of friction ranges from 30° to 32° with cohesion value of 1.08 KPa to 7.92 KPa.

Based on its load-bearing capacity, pure *Anapog* can be ideally utilized as subgrade. A mixture of 40% *Anapog* and 60% crushed stone produced CBR value that conforms to DPWH standard for base course material for road construction.

High values of friction angles, excellent compaction behavior, low compressibility, and adequate load bearing capacity manifested by weathered limestone in this study are indications that it is suitable as an alternative material for roadway construction and other engineering applications.

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