LIMESTONE: AN ALTERNATIVE MATERIAL FOR ROAD BASE AND SUBBASE

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Dedicated to my beloved family

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ABSTRACT

This study was carried out to examine the suitability of using limestone as road base and subbase materials. Limestone samples were collected, for laboratory tests, from two selected locations of Sarawak namely Akud Quarry at 21^{st} mile of Kuching-Serian Road and Paku Quarry at Bau. Crushed and on site gradated samples were used and tested for pavement design parameter, CBR. Other physical tests like sieve analysis, specific gravity and water content were also done. The test results were compared with the existing specifications for base and subbase materials of Public Works Department (JKR) of Malaysia. The laboratory test results revealed that limestone samples as collected from both the quarries need to be graded to meet the criteria of base materials as specified. However, limestone aggregate as collected from Akud Quarry site was found to meet the specifications of subbase set by JKR.

ABSTRAK

Kajian ini telah dijalankan untuk menentukan kesesuaian penggunaan batu kapur sebagai bahan untuk *road base* dan *subbase*. Batu kapur yang telah diambil untuk terlibat dalam ujian makmal adalah daripada 2 lokasi kuari di Sarawak iaitu Akud Kuari yang terletak di Batu 21, Jalan Kuching-Serian dan Paku Kuari yang terletak di Jalan Bau. Batu kapur yang telah dipecahkan dan dibahagikan mengikut saiz di tapak kuari telah digunakan untuk terlibat dalam ujian makmal, iaitu *CBR*. Selain itu, ujian makmal yang turut terlibat adalah *sieve analysis*, *specific gravity* dan *water content*. Keputusan yang diperolehi akan dibandingkan dengan nilai yang telah ditetapkan untuk road base dan subbase, iaitu Jabatan Kerja Raya Malaysia. Keputusan dari ujian makmal menunjukkan bahawa batu kapur yang diambil daripada kedua-dua kuari tidak memenuhi kriteria bahan untuk *road base*. Walaubagaimanapun, batu kapur yang telah diambil daripada Akud Kuari adalah mengikut nilai *subbase*, iaitu nilai yang telah ditetapkan oleh JKR.

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NOTATION

C.B.R	-	California Bearing Ratio
C_C	-	Coefficient curvature
C_U	-	Uniformity coefficient
cm^2	-	Centimeter square
cm^3	-	Centimeter cubic
g	-	Gram
g/cm^3	-	Gram per meter cubic
hr	-	Hour
in	-	Inch
in^2	-	Inch square
kg	-	Kilogram
kN	-	kilo Newton
lb	-	Pounds
Mc	-	Pore water mass
M_D	-	Mass dry
Ms	-	Grain mass
M_{SSD}	-	Mass saturated, surface dry
M_{SUB}	-	Mass submerged
M_{WA}	-	Mass of absorbed water
Min	-	Minute
mm	-	Millimeter
N	-	Newton
RD_A	-	Apparent relative density
RD_B	-	Bulk relative density
RD_{SSD}	-	Saturated surface-dry, relative density
V_B	-	Volume bulk
V_N	-	Volume net
W	-	Water content
^oC	-	Degress celcius
% Abs	-	Percentage absorption
%	-	Percentage
μm	-	Micrometer

ABBREVIATIONS

AASHTO	-	American Association of State Highway & Transportation Officials
ASTM	-	American Society for Testing Materials
B.S	-	British Specification
$CaMg(Co_3)$	-	Dolomite
$Ca(OH)_2$	-	Calcium Hydroxide
$CaCo_3$	-	Calcium Carbonate
$CaMg(CO_3)_2$	-	Magnesium
CaO	-	Calcium Oxide
CO_2	-	Carbon Dioxide
MgO	-	Magnesia
SiO_2	-	Amorphous Silica
TRRL	-	Transport and Road Research Laboratory

CHAPTER 1

INTRODUCTION

The purpose of this chapter is to give a briefly explanations about road pavement, limestone, and the objective of this project. This chapter also includes the scopes and limitation for this study.

1.1 General

Although it would be naïve to compare the roads constructed by the Romans more than 1800 years ago with modern highways, the sheer scale of their operations throughout the whole of Europe seems incredible even by today's standard. Throughout Europe from medieval times, stone setts were the most widely used form of pavement construction. After 1850, wood block pavements were introduced into many European cities as a less noisy alternative to stone setts. While in between 1870 and 1890, ceramic brick or block pavements were widely used in New York and other American cities. The blocks were of brick size, but only 2-3 in thick. Fracture, probably due to in adequate quality control, appears to have been the main problem with these. The use of wood blocks in London continued until the nineteen-fifties. In later years, their life was extended by tar spraying and chipping. This also ensured an adequate resistance skidding.

In 1854, asphalt was first used as a paving material in Paris. The material used was natural rock asphalt, i.e., limestone rock impregnated with asphalt. The material provided a quiet, easily cleaned surfacing but the skid resistance was very low in wet weather. By 1870, this type of surfacing was being widely used also in Britain, Germany, Switzerland and in the United States, and it continued to be used until the nineteen thirties in the city of London. Concrete roads almost certainly started in the USA in the first decade of the twentieth century, and spread to Europe in the twenties. Concrete was widely used over a century ago as a base for stone setts, wood blocks and asphalt, but it was not used as running surface.

While in Malaysia, flexible pavement or bituminous pavements were first constructed some time before the Second World War. In those years, the road pavements were constructed using block stone pitching on sand or laterite sub-base covered with a layer of tar or bitumen stabilized aggregates. Since the war, road pavements have been constructed using crushed stones road base and sub-base with dense bituminous surfacing. This construction method is still being practiced today.

1.2 Road Pavement

Pavements are classified as "rigid" or "flexible" depending on how they distribute surface loads. Rigid pavements, where the top layer is high quality concrete while flexible pavements, in which the top layers are bituminous-bound.

The function of the pavement structure is to distribute imposed wheel loads over a large area of the soil. If vehicles were to travel on the natural soil it self, shear failure would occur in the wheel path in most soils and ruts would form. The shear strength of the soil is usually not high enough to support the load. In addition to its load distribution function, the surface course of pavement structure must provide a level, safe traveling surface.

Major component of a pavement structure are surface, base, subbase and subgrade. Surface layer, which is the most expensive layer, is depended on the bearing capacity of base and subbase layer. Base and subbase are usually granular material/aggregates. Sand, gravel and laterite are amongst the various types of subbase course materials. When these materials do not have the required quality, cement stabilization of these material or crushed aggregate is to be used. The subbase, which is lower in the structures, does not require as high quality a material as the base, as loads are reduced considerably.

1.3 Limestone

Sedimentary rocks are by far the most common rock type exposed at the earth's surface. The principal sedimentary rocks are limestone, sandstone and shale. Limestone differs greatly in colour and texture, depending on the size of the shells or crystals they contain. Limestone is formed in water from the sedimentation of shells and shell fragments or chemically from the precipitation of calcium carbonate. Limestone that contains a significant amount of magnesium carbonate is called dolomite. Chalk is a porous limestone sometimes containing chert or flint nodules. Corals, i.e. animals living in warm ocean water at moderate depth, form reef limestone.

Many of the outcropping limestone have economic importance because of their thickness, lithology or composition. Because of specific chemicals or physical properties, some of the limestones are suitable for specialized uses such as for road construction, in cement manufacture, construction and building industries, production of tiles and the agricultural.

1.4 Objective

The objective of this study is to describe the characteristics of limestone to be used as an alternative material for road base or subbase. For the purpose of the study, two samples are taken from different Quarries:

i) Bukit Akud Quarry at 21st Mile, Kuching-Serian Road

ii) Paku Quarry at Bau

The methodologies employed in this study involved of California Bearing Ratio (CBR), Water Content, Sieve Analysis and Specific Gravity.

1.5 Scope and Limitation

The scope of the project includes:

i) To determine whether limestone that produced in Sarawak can be used for road construction, as a base/subbase layer.

ii) For the purpose of the study, only limestone that found at Akud Quarry and Paku Quarry are involved for laboratory testing.

iii) The scope of the project covers the laboratory testing to find the characteristics of limestone by using a few parameters such as California Bearing Ratio Test (CBR Test), Specific Gravity Test, Water Content Test and Sieve Analysis Test.

CHAPTER 2

LITERATURE REVIEW

The purpose of this chapter is to give a more thorough understanding regarding the physical and chemical properties of the limestone. This chapter also gives an in depth inside look of the pavement and their specifications that they have to meet in the same way that specifications have been drawn up for road making materials already in use.

2.1 Limestone

2.1.1 General

According to Jumikis (1983), limestone is a sedimentary rock, which is a bedded carbonate rock and consists predominantly of Calcium Carbonate ($CaCO_3$). The colors of limestones vary from white through varying shades of gray and black. Most limestones have a clastic texture, but crystalline textures are common. The carbonate rocks, dolomite and limestone, constitute about 22% of the sedimentary rocks exposed above the sea level.

The other common mineral in limestone is dolomite [$CaMg(CO_3)$]. Common impurities in limestone include chert (microcrystalline, cryptocrystalline, quartz or amorphous silica, SiO_2), clay, organic matter and iron oxides. Limestone is unique since it is soluble in even slightly acidic waters, such as carbonic acid formed from the dissolution of carbon dioxide in water. (Kong, 2002)

According to Atkins (1997), limestone and dolomite are quite common sedimentary rocks. They are softer than igneous rocks, but are still acceptable as aggregates for most purposes.

A physical feature of limestones, which is important geotechnically, is its intrinsic porosity. According to Jumikis (1983), limestones vary greatly in porosity, some being very impervious, some very porous, hence, pervious. Because carbonate rocks are relatively soluble, solution cavities in limestones may be abundant. In limestone areas solution cavities and hence permeability should always be suspected until contrary evidence is obtained. Limestone has a wide use in construction and in industry. It is also one of interior and exterior dimension stone, and it is also the basic ingredient in the manufacture of cement and lime.

2.1.2 Occurrences

Limestone is of rather wide occurrence in Malaysia. In Peninsular Malaysia, the major occurrences are in the Klang Valley, the Kinta Valley, Kedah-Perlis (including the Langkawi Islands), Kelantan (Gua Musang area) and Pahang. In these aforementioned areas, limestone occurs as majestic, precipitous cliffs as well as extensive bedrock formations. (Kong, 2002)

According to Kong (2002), no limestone hills occur in the southern regions of Peninsular Malaysia (Johor, Melaka), and at one time it was thought that limestone does not occur at all in the southern region of Peninsular Malaysia. However, in recent site investigations, boreholes, mostly associated with various engineering construction projects, have encountered limestone bedrock in some parts of Johor as well as parts of Singapore Island. For example, the Tangkak vegetable farm area is underlain by extensive limestone bedrock, as revealed by boreholes drilled for the North-South Expressway in the Tangkak area.

Sarawak and Sabah have extensive limestone formations occurring in the forms of numerous limestone hills and bedrock. The examples are the famous Mulu Caves and the Niah Caves of Sarawak. Actually, there are a lot of limestone's quarry in Sarawak such as Sin Seng Ann Quarry, Poh Kwang Quarry, Paku Quarry, Bestknown Quarry, PPES Quarry, Thump Up Quarry, Akud Quarry and Pludec Stones. For the purpose of the study, only two quarries of limestones are involved. There are Akud Quarry at Serian and Paku Quarry at Bau.

2.1.3 Formation of Limestone

Limestone consists mainly Calcium Carbonate ($CaCo_3$) and forms on the bed of the sea from the remains of sea shells and other marine organisms. Fish, shellfish, corals and marine micro-organisms extract Calcium and dissolved Carbon Dioxide from sea water to make Calcium Carbonate. Their remains settle on the sea bed where they may later be buried by other sediments.

Heat and pressure causes these animal remains to form hard beds rich in Calcium Carbonate. The remains of shells and other fossils can often be seen in limestone. If limestone is very deeply buried, heat and pressure will cause the Calcium Carbonate to recrystallize, forming marble.

2.1.4 Mining of Limestone

Underneath the topsoil, ash and siltstone is an exceptionally high grade limestone, much of it with a purity exceeding 95%. Limestone is mined in a quarry. It is then transported by truck to a crushing plant. The limestone in its natural block form is fed into a closed circuit primary impactor until it has been reduced to the required size. Different sized limestone has different applications. Different treatments produce different products from the raw material.

2.1.5 Treatment of Limestone

Burnt Lime (Calcium Oxide, CaO) is manufactured by calcining high quality limestone at very high temperatures. Nearly half the limestone's weight is volatilized off as Carbon Dioxide to produce Calcium Oxide or bunt lime. This product is commonly known as quicklime, roach lime or unslaked lime.

Hydrated Lime (Calcium Hydroxide, $Ca(OH)_2$) is a derivative of burnt lime. It is treated with water in continuous hydrators then dried. Air separators then classify the micron-sized particles. The final product appears as a fine white powder. Hydrated lime is also known as slaked lime, and is the most widely used alkali in the world.

Agricultural Lime (Calcium Carbonate, $CaCo_3$) is commonly known as lime and ground limestone. Grinding limestone to less than 2 mm produces it. Limestone Chip is Calcium Carbonate that has been crushed and screened. It is used for decorative driveways, in steel manufacturing and in coal desulphurisation.

2.1.6 Mineralogy of Limestone

Limestones can be classified either as a chemical precipitate or an organic sedimentary rock. Sea water is nearly saturated with calcium carbonate, so slight change in water temperature or chemical composition can bring about the precipitation of calcite out of solution. The more prevalent form of limestone is as an organic sedimentary rock. These are comprised of the fossil remains of sea organisms or of calcareous shell material that has been reworked and consolidated.

Limestone in its purest form is known as calcite with a chemical composition of $CaCO_3$ (Calcium Carbonate) made up of 56.0 per cent CaO (Lime) and 44 per cent CO_2 (Carbon Dioxide). Limestone often contains small quantities of impurities such as magnesium, iron, zinc, manganese and lead. Dolomite is a magnesium limestone or a carbonate of calcium and magnesium $CaMg(CO_3)_2$.. Pure dolomite contains 47.8 per cent CO_2 (Carbon Dioxide), 30.4 per cent CaO (Lime), and 21.8 per cent MgO (Magnesia). Iron and manganese carbonates are also sometimes present.

There are many varieties of limestone. It can be coarse–to very fine-grained in texture, hard to soft in compaction. Limestone may be metamorphosed to a grade where it readily accepts a good polish suitable for dimension stone and is referred to as marble.

2.1.7 Uses of Limestone

Limestone is one of man's oldest materials and is also known as the world's most versatile chemical. Thousands of years later and on the other side of the world, lime is still used on roads. Burnt Lime and Hydrated Lime are used to stabilize roads, airport runways, irrigation canals, earth dams and building foundations.

The limestone agglomerates clay particles into coarser particles through base ion exchange as well as producing a cementing or hardening action. The reaction products are permanent, producing a durable stabilizing layer. Benefits of lime use in road construction include: improved structural quality, greater load bearing capacity, reduced maintenance costs and extended life. Limestone is used to chemically treat and strengthen clay soils to form satisfactory base and subbase material.

According to Thagesen (1995), hard limestones are frequently used as aggregate in road pavements but most sedimentary rocks are soft and only suitable for embankment construction. Hard limestone may have a high abrasion and base courses. Limestone bonds well to bitumen. However, most limestones have a very low polished stone value, and asphalt surfacing made with limestone aggregates normally become slippery when wet. Hard lime is an excellent aggregate for cement concrete because of its low thermal expansion.

Limestone is widespread in many countries in the Middle East and may be the only material available to use as crushed rock aggregate. In other tropical regions reef limestone is very common. In the South Pacific and Indian Oceans many of the islands are formed entirely by corals. Several islands in the Caribbean and parts of the land mass surrounding the Bay of Mexico are formed by reef limestone raised from the sea bed. Some of this limestone is hard and can be used for pavement construction.