MEASUREMENT AND ANALYSIS OF PHYSICAL PROPERTIES OF MAJOR ROCKS IN NORTH WEST PENINSULAR MALAYSIA

By

MOHD HAFIZ BIN MUSA

Thesis submitted in fulfilment of the requirements for the degree of

Master of Science

February 2012

ACKNOWLEDGEMENTS

In the name of ALLAH, the Most Gracious, the Most Merciful. Firstly, I would like to thank Universiti Sains Malaysia for giving me this opportunity to pursue my master degree at School of Physics, Universiti Sains Malaysia. I humbly acknowledge to all my supervisors, Prof. Mohd. Nawawi Mohd. Nordin, Mr. Khairul Arifin Mohd Noh, and Assoc. Prof. Khiruddin Abdullah for all their generous supervision and patience over the last two years. I would also like to thank Mr. Zulfadhli Hasan Adli who helped me in gathering a lot of information for this project. I also like to extend my thanks to all staff of the geophysics laboratory because they helped me a lot to complete my work. Thank also to all staff in UTP (Universiti Teknologi Petronas) rock physics laboratory in helping me completing the data acquisition processes. My special thanks go to the Kementerian Sains, Teknologi dan Inovasi (MOSTI) for the “Program Pasca Siswazah” scholarship, which had supported my study. On a special note, I would like to express my humble gratitude to my parents, Mr. Musa Abdul Rahman and Mrs. Suraya Hamzah and all my family members for their support and encouragement in my life. My thesis is dedicated to them. Thank you so much.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

LIST OF ABBREVIATIONS

V_p	=	P wave velocity
V_s	=	S wave velocity
V_s-x	=	S wave velocity at X axis
V_s-y	=	S wave velocity at Y axis
UTM	=	Ultrasonic testing method
YM	=	Young modulus
SM	=	Shear modulus
BM	=	Bulk modulus
LC	=	Lame constant
PR	=	Poisson ratio

PENGUKURAN DAN ANALISIS SIFAT FIZIK BATUAN UTAMA DI UTARA BARAT SEMENANJUNG MALAYSIA

Abstrak

Semua kaedah geofizik, sama ada dalam penerokaan sumber asli atau dalam kajian struktur bumi berkait dengan sifat fizik batuan. Sifat fizik yang paling biasa digunakan dalam kajian penyelidikan geofizik adalah sifat kekenyalan, graviti tentu (atau kepadatan) dan kekuatan mampatan. Sifat-sifat fizik ini adalah asas kepada tafsiran data yang dikumpul daripada kajian penyelidikan geofizik. kajian penyelidikan ini terbahagi kepada tiga objektif. Pertama, mengkaji pengukuran parameter fizik batuan utama Malaysia dari segi sifat kekenyalan, graviti tentu atau ketumpatan dan kekuatan mampatan, Kedua, mengkaji perkaitan antara semua parameter fizik di bawah penyiasatan dan ketiga untuk membentuk satu jadual ciri-ciri fizik bagi ketiga-tiga jenis batuan (granit, batu kapur dan marmar). Semua sampel batuan dikumpul dari kawasan utara barat semenanjung Malaysia dan tiga jenis pengujian telah dilakukan iaitu kaedah ujian ultrasonik, kaedah sesaran air dan ujian titik-beban.

Secara umum, semua keputusan yang terlibat dalam kajian ini telah disahkan secara statistik berdasarkan nilai kecil nisbah antara min dan sisihan piawai. Hasil kajian menunjukkan bahawa halaju gelombang P, (V_p) adalah tertinggi di dalam batu kapur berbanding dengan batuan granit dan marmar. Keputusan ini disokong oleh nilai gravity tentu yang menunjukkan bahawa batu kapur adalah lebih padat berbanding dengan granit dan marmar. Korelasi telah dibuat antara variasi V_p keatas pemalar kenyal batuan. Secara umum, terdapat hubungan linear antara V_p dengan

semua pemalar kenyal dan disokong oleh nilai pekali korelasi linear, r. Kaedah analisis regresi telah dijalankan untuk menyiasat hubungan antara V_p dan semua pemalar kenyal. Pemalar kenyal yang terlibat adalah modulus young, (YM), modulus shear, (SM), modulus bulk, (BM), dan pemalar lame, (LC).

Korelasi yang baik telah didapati di dalam batu kapur di mana V_p berjaya dikaitkan dengan semua pemalar kenyal dan oleh itu, semua persamaan regresi yang dihasilkan boleh digunakan untuk tujuan anggaran pada masa hadapan disebabkan nilai pekali penentuan, R^2 yang tinggi. Manakala bagi batuan granit, hanya korelasi antara V_p and BM telah berjaya dikaitkan dengan R^2 yang boleh diterima. Manakala bagi batuan marmar, dua korelasi telah berjaya dikaji iaitu V_p dan BM dan V_p dan LC. Kajian mengenai hubungan antara nisbah halaju gelombang P dan halaju gelombang S, (V_p/V_s) terhadap pemalar kekenyalan menunjukkan bahawa terdapat hubung kait yang berkesan di antara nisbah V_p/V_s dan LC untuk kesemua sampel batuan berdasarkan kepada nilai R^2 yang tinggi. Secara keseluruhan, kajian ini telah berjaya menyiasat sifat-sifat fizikal batuan (sifat kekenyalan, graviti tentu atau ketumpatan dan kekuatan mampatan) bagi batuan utama di utara barat semenanjung Malaysia.

MEASUREMENT AND ANALYSIS OF PHYSICAL PROPERTIES OF MAJOR ROCKS IN NORTH WEST PENINSULAR MALAYSIA

Abstract

All geophysical methods, either in the exploration of natural resources or in the study of earth structures are related to the physical properties of rocks. Physical properties of the most commonly used in geophysical research are the property of elasticity, specific gravity (or density) and compressive strength. These physical properties are the basis for the interpretation of data collected from studies of geophysical research. The research has three objectives. Firstly, to study the physical parameters of Malaysia's major rock in terms of property of elasticity, specific gravity or density and compressive strength. Secondly, to examine the relationship between all the physical parameters under investigation, and thirdly to form a table of physical characteristics of these three types of rock (granite, limestone and marble). All rock samples were collected from the North West peninsular Malaysia and three types of tests had been conducted which include method of ultrasonic testing, water displacement method, and point-load test.

In general, all the results obtained in this study were validated statistically based on small ratio between mean and standard deviation. The study shows that the seismic P wave velocity, ($V_{p)}$ is the highest in limestone rock than granite and marble. This result is supported by the specific gravity values which indicate that the limestone is denser than granite and marble. Correlations were made between the variations of V_p toward elastic constant. In general, there is a linear relationship between V_p with all the elastic constants and the relationship had been validated by the linear correlation coefficient, (r). Method of regression analysis was conducted

to investigate the relationship between V_p and all the elastic constants. Elastic constants involved are young modulus, (YM), shear modulus, (SM), bulk modulus, (BM), and lame constant, (LC).

Good correlation had been found in the limestone where V_p were successfully correlated with the elastic constants and therefore, all the resulted regression equations can be used for future estimation due to the high coefficient of determination, (R^2). Whereas for granite rock, only the correlation between V_p and BM had been successfully correlated with the acceptable R^2. While for marble rock, two correlations had been made which are V_p and BM as well as V_p and LC. Studies on the relationship between ratio of P wave velocity and S wave velocity, ($V_p/V_{s)}$ towards the elastic constant shows that there are effective relationships between the ratio of V_p/V_s and LC for all rock samples based on the high value of R^2. Overall, this study had successfully investigated the physical properties of rocks (the property of elasticity, specific gravity or density and compressive strength) of the major rocks in North West peninsular Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The information about the physical properties of rock such as elastic properties, specific gravity or density as well as compressional strength is very useful and important. In petroleum industry especially in petrophysic investigations, the term of elastic properties also known as mechanical properties of rock are very common terminology because such information are needed in various disciplines and fields. For example, geophysicists need to know about the elastic properties which can be extracted out from well log data to improve the synthetic seismograms, seismic models, and interpretation of seismic attributes, seismic inversion, and processed seismic sections. Hydraulic fracture design engineers need to know the response of rock strength with respect to the variation of pressure environments to optimize fracture treatments. Geologist and engineers required the elastic data to investigate the in-situ stress regimes in naturally fractured reservoirs. Drilling engineers who wish to prevent accidentally fracturing a reservoir with too high a mud weight, or who wish to predict over pressure formations to reduce the risk of a blow-out also need to know the information about elastic properties.

Specific gravity or density is also important information involved in the calculation of elastic constant of rocks. Generally, density of rock is affected by the degree of porosity where the more porous rocks have lower density and vice versa. In real petrophysic works, density, elastic constants, and acoustic velocity are three parameters that needed while investigating the mechanical response of rocks. Another parameter that will be investigated in these studies was compressive strength. Rock engineers used the uniaxial compressive strength, (UCS) of rocks extensively in designing surface and underground structures. Compressive strength of rocks generally decreases with larger grain size, higher porosity and higher moisture content. In this study three physical properties were investigated which include elastic properties, specific gravity or density as well as compressive strength of rocks. The three major rock types were collected around North West region of peninsular Malaysia which comprise of granite, limestone and marble. The types of the rock had been chosen based on their major contributions towards the civil and geotechnical industry in our country.

1.1.1 Rock Physics

The connection between physical properties of rocks and geophysical parameters such as seismic velocities, specific resistivity, specific gravity and etc is known as rock physics. Michael (2009) had investigate the recent developments in seismic rock physics and stated that the major challenge of rock physics in seismic exploration is its employment in gaining and understanding of how the lithology, porosity, confining stress and pore pressure, pore fluid type and saturation, anisotropy and degree of fracturing, temperature and frequency influence the velocities and attenuation of P wave and S wave in a sedimentary rock. Rock physics describes a rock by physical properties such as elastic properties, compressive strength, rigidity, and compressibility. These properties are dependent on the composition of rock materials (texture, rock fabric, mineral, pore space, depositional and post-depositional features) and affected by pressure and temperature. In general, the knowledge about rock physics is required in doing interrelationship between observed parameters into another distribution of properties that are significant for particular geological or technical problems. The development of such interrelationships, which are fundamental for modern interpretation techniques and strategies, is an important subject of research in rock physics.

1.1.2 Research problem statement

Until today, Malaysia rock physic information is still depending on references from published works such as from Schön (1996) and Carmichael and Robert (1989) which might be different from our local observation. The range of values of the rock property from published work is wide, caused by the incident of homogeneity or heterogeneity and isotropy or anisotropy. Moreover, the data obtained are not from local rocks which in general experienced different exposure. Hence, local rock properties are needed as a database for geophysics and geology as a reference.

1.2 Objectives

The objectives of this research project are as follow:

I. To study the physical parameter of rocks in terms of elastic properties, specific gravity or density and compressive strength.
II. To obtain empirical correlation between all the physical parameters.
III. To create a database of physical properties for granite, limestone and marble.

1.2.1 Scope of Research

There are three limitations while doing investigation and experimental works throughout this project:

I. All the samples should be regarded as linear elastic homogenous isotropic solid rocks.
II. All rock samples were collected regardless of the rock grading. So there were no calculations with respect to the degree of weathering experienced by individual rock.

III. No external pressure was given to the rocks while doing ultrasonic testing method for measuring the arrival time of seismic wave.

1.3 Geology of North West peninsular Malaysia

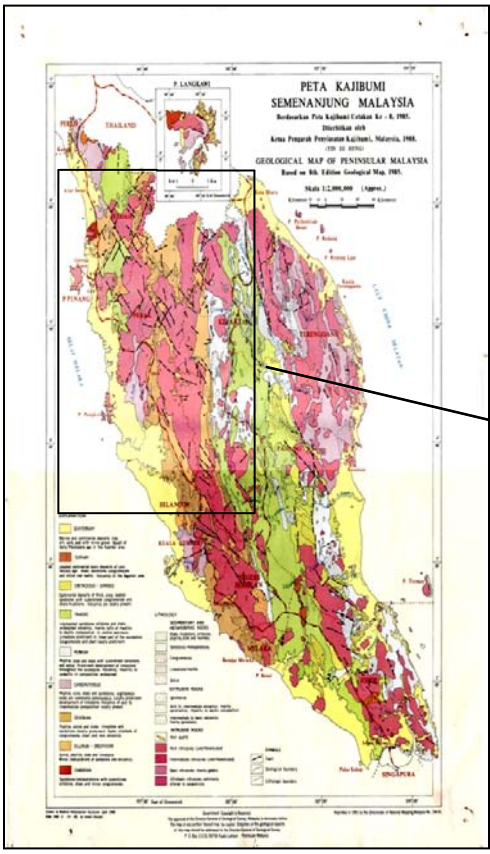
North West peninsular Malaysia comprises of four states which are Perlis, Kedah, Perak and Pulau Pinang. Figure 1.1 shows the geology map of peninsular Malaysia. In general, there are a lot of geological formations that can be found in North West peninsular Malaysia. For example, in Perlis and Kedah there are Chuping Formation or Kodiang Formation, Semanggol Formation, Kubang Pasu Formations, Setul Formation and Machincang Formation. The geological map shows that the major rock type in North West peninsular Malaysia are quaternary rocks mainly marine and continental deposit clay, silt and sand, triassic rocks which compose of sandstone, siltstone, shale and limestone, carboniferous rocks which compose of phyllite, slate, shale and sandstone, devonian rocks which compose phyllite, schist, slate and limestone, silurian to ordovician rocks which mainly schist, phyllite, slate and limestone, and a major distribution of intrusive rocks.

1.4 Study areas

In these studies, three types of rocks in North West peninsular Malaysia were collected which include samples of granite for igneous rock, limestone for sedimentary rock and marble for metamorphic rock. The samples were collected randomly regardless of their locations which involved four states which are Perlis, Kedah, Pulau Pinang and Perak. The major rock type in Perlis is limestone and shale whereas granite rock is the main rock types that form the basement of Penang Island. Apparently, granite rock is distributed more in North West peninsular Malaysia. In Perak, the limestone and marble were distributed around Kinta valley whereas granite can be found along east Perak. Granite rock samples were taken from Perak, Kedah and Penang. Whereas limestone rock samples were collected from Perlis and Kedah which involved Chuping Formation and Keriang Hill. Marble samples were collected in Perak since marble is one of the major rock types in Perak. The coordinates for all rock samples were shown in the appendix A (Table A until Table C). All the rock samples were collected randomly at these coordinates.

1.5 Outlines of the thesis

Chapter 1 presents the outline and objectives of this study. Chapter 2 contains the literature review on rock physics investigation. In chapter 2, the theoretical backgrounds that related to the experimental works were elaborated thoroughly. Chapter 3 discusses the methodology and all the equipment used in this study. The results, analyses and some descriptive discussion involved along this research were presented in chapter 4. Finally, chapter 5 represents the conclusion and the recommendation for further study.



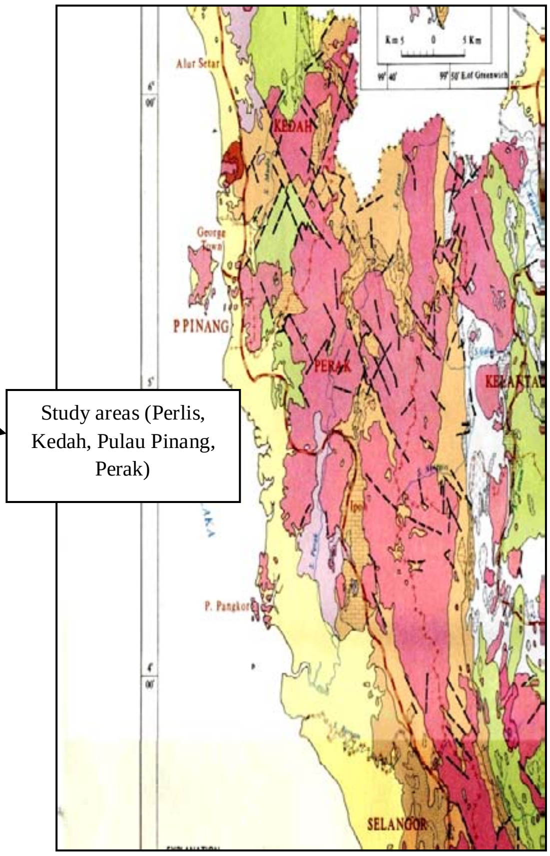
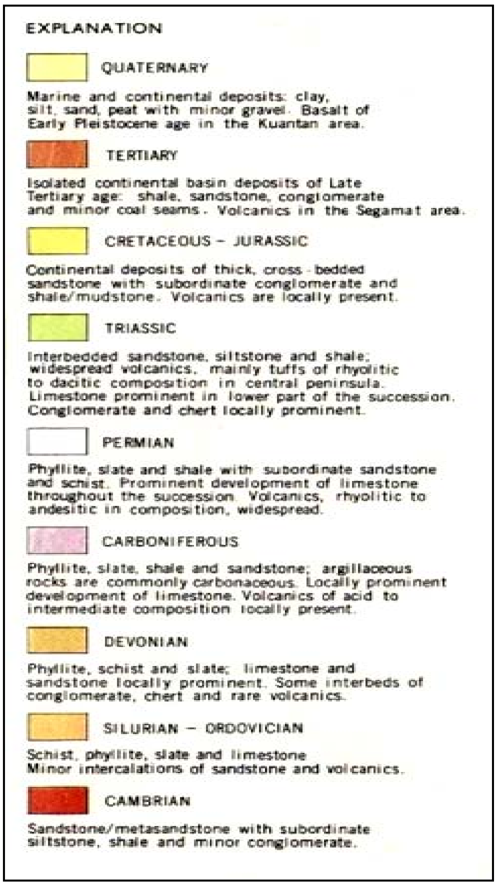


Figure 1.1: Geology map of peninsular Malaysia. Yin (1988)



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, all the theories involved in investigating all the physical properties of rock were explained in detail. The very basic information which is seismic velocities in terms of P wave velocity (V_p) and S wave velocity (V_s) can be use to calculate the elasticity of the rocks or the dynamic properties of the rocks by using a Biot Gassman equation. All the previous works related with the project were also included and shown at the end of this chapter.

2.1.1 Seismic wave

In general, seismic wave can be divided into two main groups which are body wave and surface wave. Body wave is the type of wave that propagates in the interior of the object depending on the density and the modulus of that particular object. Body wave can be subdivided into two types which are primary wave (P wave) and secondary wave (S wave). Whereas surface wave is the type of wave that propagates along the surface of the object and can be subdivided into two categories as well which are Rayleigh wave and Love wave. Nowadays, the understanding about the body wave become much more important and useful because in seismic refraction and reflection prospecting, body wave act as a main tools in visualizing the earth interior by investigating the boundary layers, density, porosity and etc. In rock physic analyses, it is well known that P wave velocity was progressively affected by the degree of porosity and the elastic properties of the rock which make the detail information about the mechanical properties of the rock such as young modulus, shear modulus, bulk modulus, poisson ratio and lame constant become very important. Another factor that greatly influences the magnitude of P wave velocity is density where magnitude of P wave is higher in the denser rock and lower in the less dense rock. In general, different rocks have different density which in turn allows different magnitude of P wave velocity.

2.1.2 Theory of elasticity

The elastic properties of solid materials are of considerable significance to both science and technology. Elasticity in general describes the mechanical behaviour of materials and thus its measurement is important for purposes of engineering design. Elastic properties are those properties which govern the behaviour of a material subjected to stress over a region of strain where the material behaves elastically. When a material is subjected to a stress it will deform; that is to say, it will become strained. It is said to be more elastic if it restores itself more precisely to its original configuration. Figure 2.1 illustrates the mechanism of stress-strain relationship.

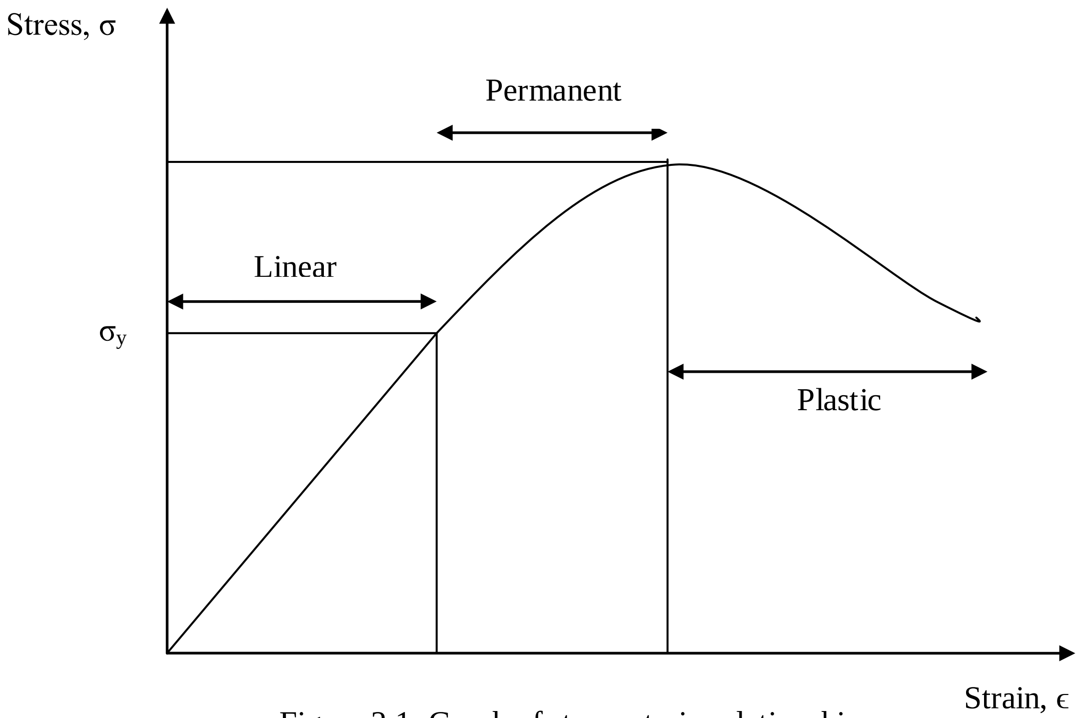


Figure 2.1: Graph of stress-strain relationships

Based on this figure, it is noticed that there is a linear relationship between stress and strain under elastic region. Over the region of stress level up to σ_y, the strain responds linearly. If the stress is reduced, the strain diminishes reversibly, and upon removal of the stress, the strain goes to zero. At a sufficiently high level of stress, the strain is no longer simply linear, and removal or reduction of the stress does not result in reversible strain. At this point a permanent deformation is produced. The material is behaving plastically. Further stressing of the material causes additional plastic deformation and finally ruptures. This behaviour is typical of most solids except those which are exceptionally brittle and which fracture in the region of elastic behaviour. As mentioned before, the relation between stress and strain under elastic region is linear relationship, so there must be a proportionality constant relating stress and strain under this region, or more precisely, elastic modulus. In this study, there are five different types of proportionality constant or elastic modulus that had been investigated which are young modulus, shear modulus, bulk modulus, poisson ratio and lame constant.

2.1.3 Elastic modulus in linearly isotropic solid

Elastic properties will explain to us about the mechanical behaviours of rock in response to the environmental changes in terms of external force, pressure and etc. For example, under certain amount of external stress, rock as a matter would have a tendency to change it shape due to overburden of stress and the degree of deformations can be explained by using the principle of elastic modulus. As mentioned before, the basic assumption in investigating the elastic properties of granite samples throughout this study was all rock samples is assumed to be consolidated linear homogeneous isotropic solid medium. The elastic modulus of an isotropic body may be expressed in a variety of ways. It can be shown that any two are sufficiently complete to describe elastic behaviour, and that any elastic modulus may be expressed in terms of any other pair. Total numbers of five types of elastic modulus were covered in these works which are young modulus, shear modulus, bulk modulus, poisson ratio and lame constant.

Young modulus is the most elementary notions in considering the strength of a solid material. In engineering applications, materials are employed in such a manner as to make this property an important design parameter, for this modulus relates a unidirectional stress to the resultant strain. Basically, young modulus is taken as the measure of the resistance to traction along the axis of a thin bar or rod. The mechanism of this modulus is illustrated in Figure 2.2.

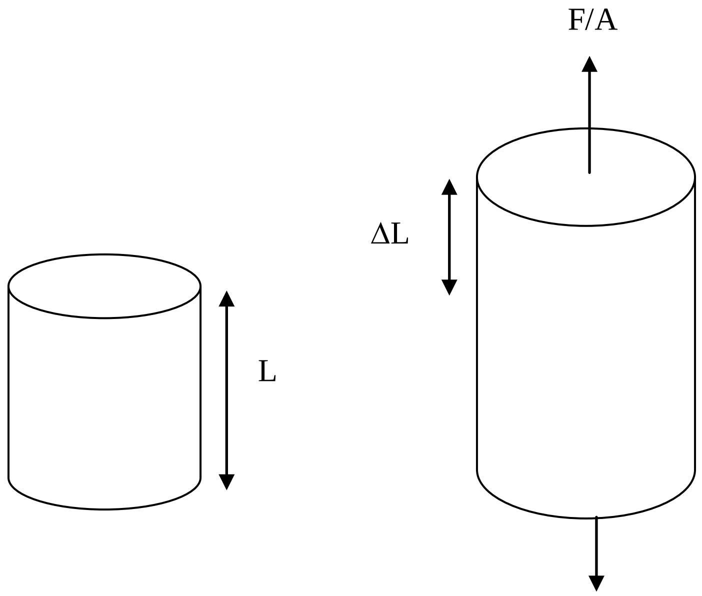


Figure 2.2: Young modulus illustration

Based on this figure, a rod or bar shown is subjected to a uniaxial stress and is strained as a consequence. The resulting strain is manifested by an elongation in the direction of the applied stress and a decrease in the diameter of the rod. The change in length divided by the initial length $\Delta L/L$ is the strain, and the ratio of the stress to the strain is young modulus. The values of young modulus of all rock samples were calculated by using equation 2.1.

$$E = \frac{2\,(1\ + \gamma)}{\mu} \qquad (2.1)$$

Where E is a young modulus, γ is a poisson ratio and μ is a shear modulus.

In addition to elongation in the direction of the axially applies stress, the rod simultaneously narrows. This change in dimension in a direction that is perpendicular to the direction of the applied stress develops from an interaction of the strain components that are generated within the material as a consequence of being stresses, principally as a volume-conserving strain. So, additional elastic modulus is needed to describe this behaviour. This is represented by poisson ratio as shown in Figure 2.3.

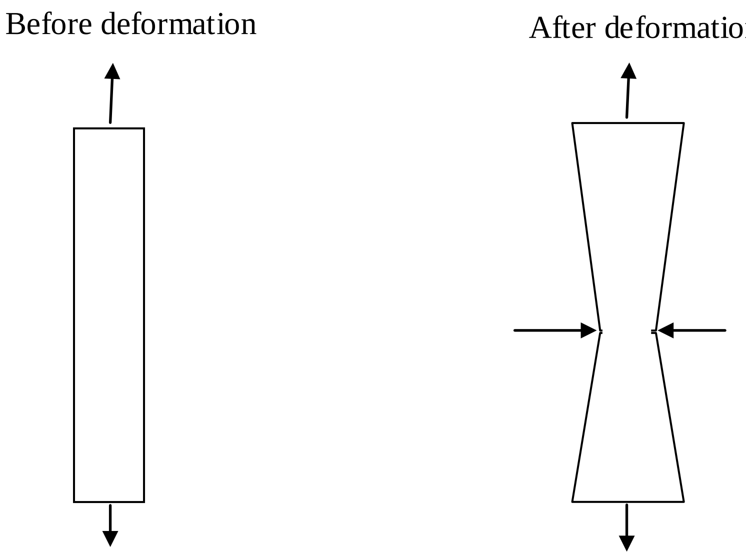


Figure 2.3: Poisson ratio illustration

Poisson ratio is defined as the ratio of change in dimension in lateral direction to the change in length. The values of poisson ratio of all rock samples were calculated by using equation 2.2.

$$\gamma = \frac{\left(1 - 2\left(V_s/V_p\right)\right)^2}{\left(2 - 2\left(V_s/V_p\right)\right)^2} \qquad (2.2)$$

Where γ is a poisson ratio, V_s is a velocity of S wave and V_p is a velocity of P wave.

For isotropic materials two fundamental properties arise as a result of subjecting the material to two different states of stress. These are the bulk modulus, where the strains perpendicular to the stress directions are all equal (hydrostatic pressure), and shear modulus, where the strains perpendicular to the stress direction are everywhere zero (pure shear). The mechanism of both bulk modulus and shear Modulus were illustrated in Figure 2.4 and Figure 2.5.

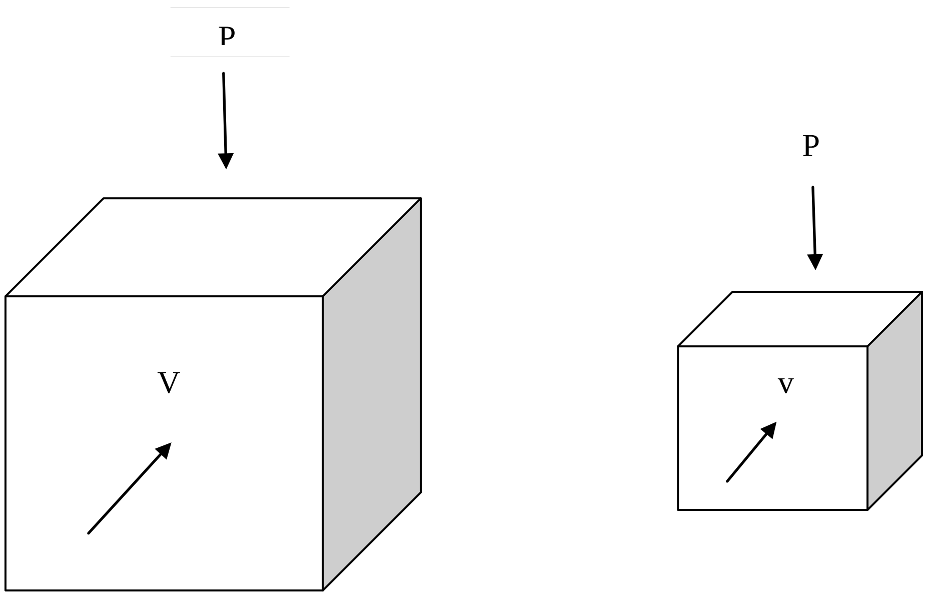


Figure 2.4: Bulk modulus illustration

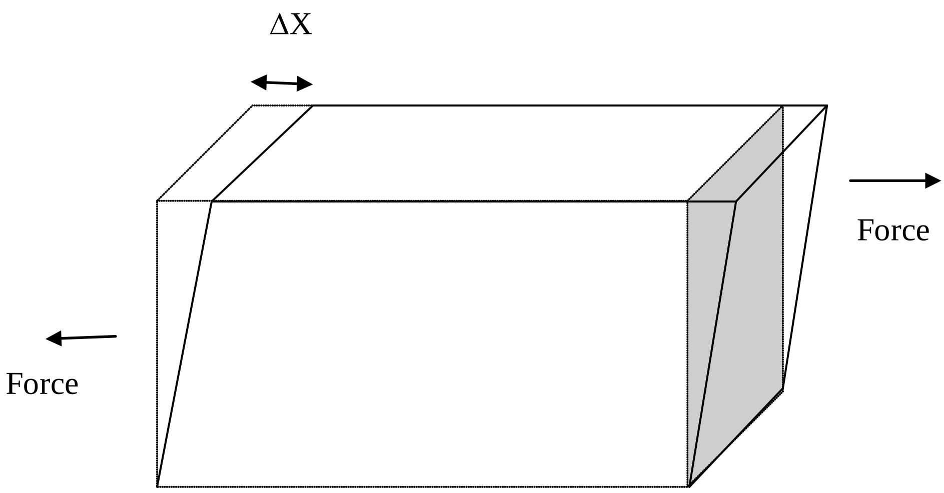


Figure 2.5: Shear modulus illustration

The values of bulk modulus and shear modulus of all rock samples were calculated by using equation 2.3 and equation 2.4.

$$K = \left(\frac{2(1+\gamma)}{3(1-2\gamma)}\right)\mu \qquad (2.3)$$

$$\mu = pV_s^{\ 2} \qquad (2.4)$$

Where K is a bulk modulus, γ is a poisson ratio, μ is a shear modulus, p is a density and V_s is a velocity of S wave or transverse wave.

Another elastic constant involved in these studies was lame constant. This constant shows the stiffness matrix of the Hooke Law and was calculated by using equation 2.5.

$$\lambda = k - \frac{2}{3}\mu \qquad (2.5)$$

Where λ is a lame constant, K is a bulk modulus and μ is a shear modulus.

2.2 Literature review

This study was the first research in Malaysia that work based on the development of rock physical properties database. The primary advantage of non-destructive ultrasonic testing is that it will preserve the sample under investigation to its original conditions. For this reasons, this techniques was widely applied especially in doing rock physics investigation. Prikryl et al. (2004) had investigated the correlation of field seismic refraction data with 3-D laboratory ultrasonic sounding data during exploration of a dimension stone deposit. He concluded that the P wave velocity pattern recorded from laboratory measurements can be satisfactorily correlated with the anisotropy of P wave velocity data acquired from field seismic refraction data. Zappone et al. (2008) had investigated the laboratory measurement of seismic P wave velocities on rocks from the Betic chain (Southern Iberian Peninsula). Matusinovic et al. (2004) had studied the correlation between compressive strength and ultrasonic parameters of calcium aluminate cement materials. In this paper, linear relationship between compressive strength and the product of the amplitude and angular frequency of the signal was established.

The main objectives of all previous studies were to produce the empirical relationship that correlate between two physical properties of rock by applying the regression analysis. Kahraman et al. (2008) determined the fractured depth of rock blocks from P wave velocity by using ultrasonic testing. In this study, inverse linear relations between the fracture depths and the P wave velocity had been found. Wyllie et al. (1956) studied the elastic wave velocities in heterogeneous and porous media by using an ultrasonic velocity meter. This study produced graphically experimental relationships between wave velocity, porosity, pore content and matrix nature of sedimentary rocks. Vasconcelos et al. (2008) investigated the ultrasonic evaluation of the physical and mechanical properties of granites. Statistical correlations between ultrasonic pulse velocity with the mechanical and physical properties of granites were presented and discussed. This works concluded that the ultrasonic pulse velocity can be actively used as a simple and economical non-destructive method for a preliminary prediction of mechanical and physical properties of rocks. Castagna et al. (1985) investigated the relationships between the compressional wave and shear wave of silicate rock and found that for water-saturated clastic silicate rocks, shear wave velocity is approximately linear related to the compressional wave velocity and the compressional-to-shear wave velocity ratio decreases with increasing compressional velocity. Kahraman and Yeken (2008) carried out the investigation in determining the physical properties of carbonate rocks from the P wave velocity and found the strong linear correlations between P wave velocities with all physical properties of rocks. Mockovciakova and Pandula (2003) studied the relation between static and dynamic moduli of rocks by using two different experiments which are non-destructive ultrasonic testing method and by using uniaxial compression test. Mabrouk and Pennigton (2009) investigated the compressional and shear wave velocity in terms of petrophysical parameters in clean formations by using neutron, density, gamma ray logs and poisson ratio and successful to produce the empirical equation that can be apply in the real field data in the northern part of the Gulf of Suez basin. Song et al. (2004) studied the determination of the elastic modulus set of foliated rocks from ultrasonic velocity measurements and they revealed that the foliation of the metamorphic rocks induce velocity anisotropy between two orthogonal direction of foliation. Wang et al. (2009) carried out an experiment in correlating the compressional and shear wave velocities with the corresponding poisson ratio for some common rocks and sulfide ores. These studies suggest that poisson ratio is linearly correlated with V_s, V_p, shear modulus and young modulus for the types of rocks and sulfide ores under investigation. Susan et al. (1991) studied the relationship between elastic-wave velocities and density in sedimentary rocks which is sandstone and limestone and found strong velocity density relationship for limestone rock but weak relationship for sandstone. Kahraman (2002) estimated the direct P wave velocity value of intact rock from indirect laboratory measurements and produced the acceptable empirical equation generated based on the regression analyses. Chang et al. (2006) produced the empirical relations between rock strength and physical properties in sedimentary rocks. In this study, 31 empirical equations are summarized that relate unconfined compressive strength and internal friction angle of sedimentary rocks (sandstone, shale, limestone and dolomites) to physical properties such as velocity, elastic modulus, and porosity. Khandelwal and Singh (2009) studied the correlation of static properties of coal measures rocks with P wave velocity. The objective of this work is to correlate compressive strength, tensile strength, shear strength, density, young modulus, and poisson ratio of the coal measures rock with the P wave velocity. Khandelwal and Ranjith (2010) investigated the relationship of index properties of rocks with P wave measurements and found good linear relationships between all the index properties determined and the P wave measurements. Kahraman (2007) studied the correlations between the saturated and dry P wave velocity of rocks and strong linear correlation between the dry and wet rock P wave velocity was found by using the regression analyses. Arslan et al. (2008) investigated the correlation of unconfined compressive strength with young modulus and poisson ratio in gypsum from Sivas Turkey and produced high coefficient determination of regression equation among compressive strength, young modulus, and poisson ratio. Starzec (1999) studied the dynamic elastic properties of crystalline rocks from South-West Sweden and had made a comparison between static testing and dynamic testing. This study had proposed an empirical relationship between P wave velocity and density and high correlation coefficient between static and dynamic elasticity was obtained and an empirical linear equation was derived. Del Rio et al. (2006) investigated the ultrasonic characterization of granites obtained from the industrial quarries of Extremadura (Spain). This work had analysed the physical and mechanical properties by means of alternative methods including destructive techniques such as strength, porosity, absorption, and etc. Some results obtained by destructive techniques have been correlated with those found using ultrasonic techniques. Al-Shayea and Naser (2004) analysed the effects of testing methods and conditions on the elastic properties of limestone rock. This study investigated the effect of cyclic loading, unloading, and reloading condition towards the dynamic elastic modulus and poisson ratio. Based on the literature reviews, it was shown that the information of rock physical properties such as P wave velocity and S wave velocity were important and can be relate to other rock physical properties.

Several previous works had been carried out to investigate the relationship between rock physics parameters such as elastic properties, seismic velocities towards the reservoir properties such as the fluid viscosity, porosity and permeability and etc. Wang et al. (2009) had investigated the seismic velocities, density, porosity, and permeability measured at a deep hole penetrating the Chelungpu fault in central Taiwan. This paper studied the depth variation in seismic velocities, porosity and permeability, the relationship between P and S wave velocity, porosity-dependence of P and S wave velocities and their ratio, and porosity-dependence of density. Dodds et al. (2007) had carried out the experimental and theoretical rock physics research with application to reservoir, seals and fluid processes. This paper describes a range of geophysical research activities at the Australian Resources Research Centre based around the development of experimental capabilities to validate the theoretical and numerical modelling predictions of geophysical properties of reservoir and seals. Saenger et al. (2011) had investigated the effect of fluid viscosity on effective elastic properties. William et al. (2003) had made a comparison of P and S wave velocity profiles obtained from surface reflraction/reflection and downhole data. Bala et al. (2009) had studied the dynamic properties of the Quaternary sedimentary rocks and their influence on seismic site effects in Bucharest city Romania. Scheu (2006) et al. had studied the temperature dependence of elastic P and s wave velocities in porous Mt. Unzen dacite. Asmani et al. (2001) had carried out the investigation on the influence of porosity on young modulus and poisson ratio in alumina ceramics. Yasar and Erdogan (2004) had investigated the correlation of sound velocity with the density, compressive strength and young modulus of carbonate rocks. Trampet et al. (2001) had studied the sensitivities of seismic velocities to temperature, pressure and composition in the lower mantle. Wang et al. (2005) had investigated the pressure dependence and anisotropy of p wave velocities in ultrahigh-pressure metamorphic rocks from the Dabie-Sulu orogenic belt (China). Benson and Wu (1999) had carried out the research to produce a modelling solution for predicting the dry rock bulk modulus, rigidity modulus, seismic velocities and reflection coefficient in porous, fluid-filled rocks with application to laboratory rock samples and well logs. Diallo and Appel (2000) had studied the acoustic wave propagation in saturated porous media to reformulate the Biot/Squirt flow theory. Avar et al. (2003) had investigated the porosity dependence of the elastic modulus of lithophysae-rich tuff which involved the numerical and experimental investigation. Jaya et al. (2010) had investigated the temperature dependence of seismic properties in geothermal rocks at reservoir conditions. Gueguen and Schubnel (2003) had carried out the investigation to study the elastic wave velocities and permeability of cracked rocks. Phir and Sangha (1973) had studied the relationship between size, deformation and strength for cylindrical specimens loaded in uniaxial compression. Wepfer and Christensen (1991) had investigated a seismic velocity confining pressure relation with application. King and Shams-Khamshir (1998) had studied the petrophysics studies of sedimentary rocks from a cross-hole seismic test site. Pyrak-Nolte (1996) had investigated the seismic response of fractures and the interrelations among fractures properties. Johnston and Christensen (1993) had studied the compressional to shear velocity ratios in sedimentary rocks. Eissa and Kazi (1988) had carried out the experiment to find the correlation between static and dynamic young modulus of rocks. Homand et al. (1993) had investigated the characterization of the moduli of elasticity of an anisotropic rock using dynamic and static methods.

So, through out this research, an investigation of rock physics had been made to find the correlation between P wave velocity and other physical properties as shown in chapter 4.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

The important methods used in this investigation were ultrasonic testing method for elasticity investigation, principle of water displacement for specific gravity or density studies and the point load test for compressional strength measurement. In this chapter, all the experimental procedures will be described.

3.2 Sample preparations

Table 3.1, 3.2 and 3.3 shows the distribution of all rock samples taken throughout these studies. The rock samples were fresh so that no consequences due to the weathering effects had been investigated through out this research. Before starting the laboratory works, all rock samples were drilled by using diamond core drill. The specification of the rock samples is 43.44 mm in diameter but with variable length, Plate 3.1. Then after that, the samples were cut in cylindrical shape with flat surface at both ends. This is imperative because during ultrasonic testing, the contact between both traducers (transmitter-receiver) and rock sample should be in a better orientation for better energy transfer. The condition of rock that was investigated in these studies is dry condition. For a preparation of dry condition of rock, all rock samples were dried by using oven at temperature 100°C for almost two weeks and then the zero moisture content of dry rocks were preserve at room temperature (26°C) by using desiccators. Plate 3.2, Plate 3.3 and Plate 3.4 shows the apparatus used while preparing the rock samples before starting the experimental works.

Table 3.1: Details for limestone rock sample

Sample	Length, m	Location	Source
K1	0.05	Kedah and Perlis	Roadside Outcrop
K2	0.06		
K4	0.07		
K5	0.04		
K6	0.08		
K7	0.06		
K8	0.08		
K9	0.06		
K10	0.04		
K11	0.07		
K12	0.04		
K13	0.04		
K15	0.07		
K16	0.04		
K17	0.04		
K18	0.05		
K19	0.06		
K20	0.07		
K21	0.07		
K22	0.04		
K23	0.06		
K24	0.07		
K25	0.06		
K26	0.07		
K27	0.05		
K28	0.05		
K29	0.05		
K30	0.07		
K31	0.06		
K32	0.04		
K33	0.05		
K34	0.04		
K35	0.05		
K36	0.05		
K37	0.05		
K38	0.05		
K39	0.05		
K40	0.04		
K41	0.04		
K42	0.04		
K43	0.05		
K44	0.04		

Table 3.2: Details for granite rock sample

Sample	Length, m	Location	Source
G1	0.07	Kedah, Penang and Perak	Roadside outcrop/Waterfall outcrop/Quarry outcrop
G2	0.05		
G3	0.03		
G4	0.08		
G5	0.08		
G6	0.08		
G7	0.06		
G8	0.07		
G9	0.03		
G10	0.04		
G11	0.03		
G12	0.07		
G13	0.03		
G14	0.07		
G15	0.03		
G16	0.04		
G17	0.04		
G18	0.03		
G19	0.04		
G20	0.03		
G21	0.04		
G22	0.02		
G23	0.04		
G24	0.04		
G25	0.04		
G26	0.04		
G27	0.06		
G29	0.03		
G30	0.03		
G31	0.05		
G32	0.06		
G33	0.05		
G34	0.04		
G35	0.08		

Table 3.3: Details for marble rock sample

Sample	Length, m	Location	Source
P1	0.069	Perak	Quarry outcrop
P2	0.053		
P3	0.052		
P4	0.064		
P5	0.058		
P6	0.075		
P9	0.054		
P10	0.051		
P11	0.040		
P12	0.069		
P13	0.047		
P14	0.050		
P15	0.049		
P16	0.057		
P17	0.059		
P18	0.062		
P19	0.048		
P21	0.033		
P22	0.042		
P23	0.053		
P24	0.068		
P26	0.066		
P27	0.069		
P29	0.057		
P30	0.064		
P31	0.072		
P32	0.048		
P33	0.053		
P34	0.049		
P35	0.048		
P36	0.045		
P37	0.052		
P38	0.049		
P39	0.045		
P40	0.050		
P41	0.049		
P42	0.046		

Plate 3.1: Rock samples

Plate 3.2: Diamond rock driller

Plate 3.3: Oven and desiccator

Plate 3.4: Rock cutter