# THE EFFECT OF MATERIAL NON-LINEARITY ON THE PREDICTED PERFORMANCE OF ROAD PAVEMENT

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For those I have over looked - Thank You Very Much.

**DEDICATION**

*I would like to forward my appreciation to my father and mother,*
*to my family who have been giving me*
*the moral support,....*
*To my wife Norizah Bte Mesdi,*
*thank you for sacrificing and the commitment support,....*
*To my son Muhammad Afiq Amsyar and my daughter Nor Balqis MayangSari,*
*you are my love and follow the way which have been given,....*
*and*
*Thank you to those who brought me to be critical thinking.*

## ABSTRACT

The purpose of this study is to determine the effect of non-linearity of unbound granular material as base course on the road pavement. This study focused in the determination of the effect of density and level of stress on resilient modulus at granular base material under repeated loading. The granular material was compacted at optimum moisture content of the 90 %, 95 % and 100 % of maximum dry density. The stress application assign to the stress situation caused by wheel loading affected at the base, upper subbase and lower subbase layer pavement. From the test result, the graph was plotted by regression analysis and the model fitted base on Brown and Pell, 1976, as $Mr = k1\ (\theta/\theta_0)^{k2}$. The result obtained was analysed by Analysis of Variant (ANOVA) using t-test to determine the effect of resilient modulus on density and level of stress. The resilient modulus increases as the level of stress and density increase, which means that the resilient modulus of unbound granular material is stress dependent and the relationship is non-linear. The effect of non-linear unbound granular material on the road pavement is determined by MICH-PAVE software. The flexible pavement was analysed based on Manual of Pavement Design (JKR) which the standard and construction layer thickness was taken. The analyses consist of the maximum horizontal tensile and the average compressive strains in asphalt layer and compressive strain at the top subgrade. These strains are related to the fatigue life and rut depth of asphalt pavement. The resilient modulus increases with the increase in density. Everything being equal pavement with unbound layer with lower may have a higher horizontal or radial strain at the bottom of asphalt, and therefore will have shorter fatigue life. The lower density at the unbound layer tends to increase the average compressive strain within the asphalt layer and compressive strain at the top of subgrade, which may cause at the increment rate total plastic deformation at the pavement.

# ABSTRAK

Kajian ini adalah bertujuan untuk mendapatkan kesan tidak linear bahan batu baur sebagai lapisan tapak didalam turapan jalan raya. Kajian ini adalah untuk mendapatkan kesan dari ketumpatan dan peringkat tekanan (stress) keatas resilient modulus pada lapisan tapak apabila beban ulangan dikenakan. Bahan batu baur dipadatkan pada kandungan lembapan optima iaitu 90 %, 95 % dan 100 % ketumpatan kering maksima. Tekanan akan dikenakan sebagai mengandaikan keadaan di jalan raya yang disebabkan oleh beban tayar kenderaan pada lapisan tapak, sub tapak dan bahagian bawah sub tapak lapisan turapan. Dari ujikaji ini, graf akan diplotkan dengan menggunakan analisis regression dan model dibangunakan berdasarkan Brown dan Pell, 1976, iaitu $Mr = k1\ (\theta/\theta_0)^{k2}$. Analisis of Variant (ANOVA) menggunakan t-test digunakan untuk mendapatkan kesan resilient modulus keatas ketumpatan dan peringkat tekanan(stress). Nilai resilient modulus akan meningkat apabila peringkat tekanan (stress) dan density meningkat, ini bermakna nilai resilient modulus untuk batu baur adalah bergantung kepada beban yang dikenakan dan pertaliannya adalah tidak linear. Kesan ketidak linearan batu baur keatas lapisan turapan diperolehi dengan menggunakan perisian MICH-PAVE. Turapan lentur dianalisa berdasarkan kepada Manual Pavement Design (JKR) dimana ketebalan lapisan pembinaan yang standard digunakan. Analisa ini meliputi kesan mendatar maksima (maximum horizontal tensile) dan purata mampatan keterikan (average compressive strains) didalam lapisan asphalt dan keterikan mampatan (compressive strain) keatas lapisan atas sub tapak. Keterikan ini mempunyai perkaitan jangka hayat dan kesan ke atas lapisan turapan. Nilai resilient modulus meningkat dengan meningkatnya peringkat keterikan. Keadaan ini memberikan kesan keatas keterikan mendatar dan pugak didalam lapisan asphalt. Peringkat mampatan yang rendah akan memberikan kesan keterikan yang tinggi dan menyebabkan jangka hayat turapan jalan akan menjadi lebih singkat.

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## SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| $M_r$ | Resilient modulus |
| $E$ | Elastic Modulus ($kg/cm^2$) |
| $\upsilon$ | Resilient Poisson's ratio |
| $\sigma_1$ | Axial stress (kPa) |
| $\sigma_2$ | Radial stress (kPa) |
| $\sigma_3$ | Confining stress (kPa) |
| $\sigma_c$ | Deviator or cyclic stress |
| $\varepsilon_{ax,res}$ | Resilient axial strain |
| $\varepsilon_{rad,res}$ | Resilient radial strain |
| $\theta$ | Sum of principal stresses (kPa) |
| $\theta_o$ | reference value (1 kPa) |
| $k_1, k_2$ | regression coefficients |

# LIST OF APPENDICES

CHAPTER I

# INTRODUCTION

## 1.1 Introduction

Pavement is the structure which separates the tires of vehicles from the underlying foundation material. Pavement is normally consist of multilayer construction with relatively weak materials below and progressively stronger ones above. Such an arrangement leads to the economic use of available material.

Road pavements in Malaysia have traditionally been classified as flexible pavement and rigid pavement. The flexible pavement usually consists of three main layers, the bituminous surfacing, the base or road base and the sub base, and for the rigid pavement consists of two layers, concrete slab and the subbase.

The surfacing is generally divided into the wearing course and the binder course laid separately. The base and sub base may also be laid in composite form using different materials designated the upper and lower base or sub base. Where the soil is considered very weak, a capping layer may also be introduced between the sub base and the soil foundation and generally referred to as the sub grade and the surface of the sub grade is termed the formation level.

The rigid pavement is cement concrete pavements and normally consist of two layers only, the concrete slab and the subbase. The slab may be laid in composite form using different aggregates in the upper and lower layers. Concrete pavements may be reinforced with steel mesh or they may be unreinforced. The function of the reinforcement is to hold any cracks which form from opening and is intended to distribute cracks uniformly along the length of the pavement, the intention being to prevent isolated wide cracks.

## 1.2 Pavement Issues

The incremental of traffic volume will create the congestion of the roads and will detriorate the pavements and reduces its lifetime. The increase of load and the number of load repetitions on the pavement may induce permanent deformation and fatigue cracking on the bounded layer in pavement layer structure. The maintenance and reconstruction may involve a high investment cost.

## 1.3 Pavement Design

The road pavement design related to traffic, design life and pavement thickness for various forms of pavement. Methods of pevement design can be classified as *empirical and mechanistic-empirical methods.*

The *empirical method* is used without a strength test dates back to the development of the Public Roads soil classification system in which subgrade was classified as uniform from A1 to A7 and nonuniform from B1 to B3. The system was later modified by the Highway Research Board in 1945 in which soils were grouped from A1 to A7 and was added to differentiate the soil within each group. The empirical method with a strength test was used by the California Highway Department in 1929 in which the thickness of pavements was related to California Bearing Ratio, defined as the penetration resistance of the sub grade soil relative to trhe standard crushed rock. The disadvantage of this method is that it can be applied only to given set of enviromental, material and loading conditions. If the conditions are changed, the design is no longer valid and new method must developee through trial and error to be commensurate with the new conditions (Huang, 1993).

*The mechanistic-empirical method* of design is based on the mechanics of materials that the relates an input, such as a wheel load, pavement response such as stress or strain. The response values are used to predict distress based on laboratory test and field performance data. The concepts of design pavement was based on vertical compression and horizontal tensile strain. The vertical compressive strain on the surface of subgrade was used to control permanent deformation based on fact that plastic strains are proportional to elastic strains in paving materials, and harizontal tensile strain at the bottom of asphalt layer was to minimize fatigue cracking. The advantages of this method are improvement in the realibility of a design, the ability to predict the types of distress, and feasibility to extrapolate from limited field and laboratory data (Huang, 1993).

## 1.4 Problem of Statement

The problem statement for the thesis are as follows:

i) Manual pavement design by Jabatan Kerja Raya (JKR) 1995 is based on empirical method (ASSHTO – 1972).

ii) Adaptation ASSHTO Design Guide 1972 to Malaysia conditions based on an assumption that all materials behave as linearity elastic anisotropic.

iii) In the reality, the unbound material is non-linear.



## 1.5 Objective of The Research

The objective of the study, are as follows:

i) To determine the non-linearity characteristic of the unbound granular material as per JKR specification.

ii) To determine the effect of a non-linearity of unbound granular material on the road performance.

## 1.6 Scope of Works

The scopes of work for the thesis are as follows:

i) To review the literature on the unbound material characteristics and is effects on the road pavement performance, and to determine the characteristic of unbound material as per JKR specification.

ii) To analyse effect of material non-linearity on the response of the typical pavement under standard axial load using available computer program.

iii) To predict the performance of pavement based on the pavement structural responses.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Introduction

Pavement design evolved from the 1930's, with early methods solely based on empirical relationships. From 1950 onwards the increase in road transportation led to development of more sophisticated methods, initially for flexible pavements only based on solid relationships between theory and field observations and with pavements incorporating cement bound and similar stabilized materials.

Design of flexible asphalt pavements design based on primarily upon a theoretically related analysis involving some empirical modifications. Flexible pavements were classified by a pavement structure having a relatively thin asphalt-wearing course with layers of granular base and subbase being used to protect the subgrade from being over stressed. This type of pavement design was primarily based upon empiricism or experience, with theory playing only a subordinate role in the procedure.

## 2.2 The Principles of Pavement Design

Before designing a pavement, it is essential to understand the process which influence the behaviour of pavement under the action of time and traffic. These processes are rather different for flexible and rigid pavement and considered separately below.

### 2.2.1 Flexible Pavements

As soon as traffic begins to flow over a flexible pavement, permanent deformation will start to develop in the area of the wheel tracks followed by the commercial vehicles. This permanent deformation in a well-designed pavement is evenly distributed between the asphalted materials, the unbound base and sub base, and the sub grade. In bituminous materials, it may arise from additional compaction under traffic and from sideways displacement. In unbound materials and sub grade it will be due to traffic compaction, and only in vary under designed pavements will shear in the sub grade be involved (Croney, 1998).

Wheel loads subject all pavement layers to vertical compressive stress. The wearing course, the binder course, and any bituminous base material will also be subject to tensile stress as the wheel load passes. The magnitude of this tensile stress in each layer will be determined by the effective modulus of elasticity of the layer and will be greater at the bottom of the layer. Lower bituminous layers will be subject to smaller tensile stress. Unbound granular materials used in bases and sub bases cannot accept significant tensile stress, and the structure of such layers will relax under load, so reducing the effective elastic modulus of the materials (Croney, 1998).

Structural failure will generally be initiated by fatigue cracking in the wearing course, followed by similar cracking in the binder course and any other bituminous layers.

### 2.2.2 Rigid Pavements

Rigid pavement or concrete pavements are not susceptible to surface deformation under traffic, and the normal process of structural deterioration is indicated by cracking. Wheel loads give rise to tensile- stress in the underside of the slab, which in an under designed pavement give rise to fatigue cracking. Both the compressive and flexural strength of concrete increase considerably with age, and this process continues significantly up to a life of 10 years. The increase in flexural strength will of course increase the tensile stress at the underside of the slab generated by a wheel load (Croney, 1998).

## 2.3 Granular Material as Base Course

In both flexible and rigid pavement, poor performance of unbound granular material contributes to reduce life and costly maintenance. The gradation of particle size distribution, density and moisture content of the material are factors that significantly influence the response of a granular material. These factors were accounted for in the preparation and selection of the sample for testing. They are not directly in the constitutive equation. Under the foregoing stated assumption that dominant aspect of the response of granular material is its non-linear character. The stress-strain character of the granular as expressed by the tangent modulus could be expressed as a function of the octahedral normal and shear stress (Nair et. al, 1973).

A base course is defined as the layer of material that lies immediately below the wearing surface of a pavement, and the sub base is a layer of material between the base and sub grade. Sometimes the material under a rigid pavement is called a subbase. Base courses may be constructed of stone fragments, slag, soil-aggregate mixtures and cement-treated granular materials. The function of the base course varies according to type of pavement. Base courses are used under rigid pavements and flexible pavement. For rigid pavement base course was used to prevention of pumping and prevention of volume change of the sub grade, to provide drainage and structure layer deformation. For flexible pavement base courses was used as base and sub bases to increase the load-supporting capacity of the pavement by providing added stiffness and resistance to fatigue as well as building up relatively thick layers to distribute the load through a finite thickness of pavement. This is the prime requirement of the base course and although to provide drainage when necessary (Yoder et. al, 1975).

## 2.4 Characteristics of Unbound Granular Material

A fundamental requirement for an analytical approach towards a pavement design is a proper understanding of the mechanical properties of the constituent materials. The unbound granular materials, base and sub base layers in a flexible pavement play an essential role in the overall structural performance of the pavement, tests where in-situ stress conditions and traffic load are adequately simulated are needed. Repeated load triaxial testing is one such method. The most important parameters evaluated in repeated triaxial testing are the stiffness characteristics of the material as well as the ability to withstand the accumulation of permanent deformation during pulsating loading. Figure below is illustrating the general stress regime experienced by an unbound base course element in a pavement structure as the result of a moving wheel load within the plane of the wheel track. Due to the wheel load, pulses of vertical and horizontal stress, accompanied by a double pulse of shear stress with a sign reversal, affect the element (Magnusdottir, 1996).

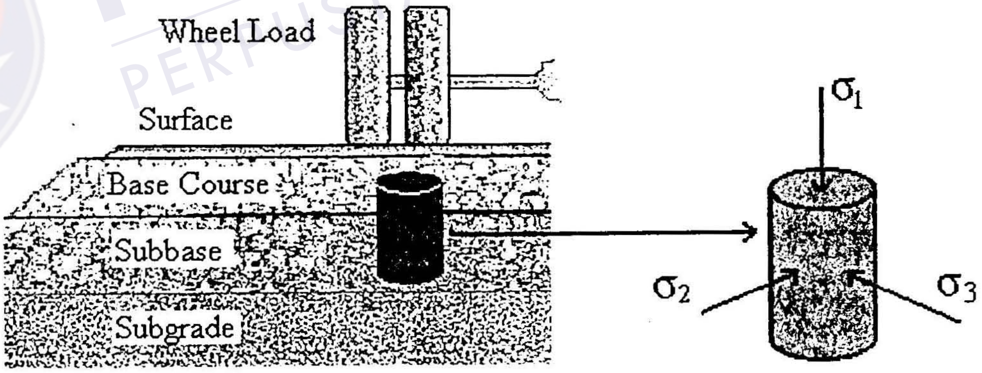


Figure 2.0: Stress in an unbound Granular material

Usually in a road structure the largest part of the strains is caused by the elastic response with only a small part due to plastic behaviour. In the laboratory where this is simulated the elastic response reflects the stiffness characteristics of the specimen but the plastic strains gives information about the permanent deformation behaviour of the specimen. During triaxial testing of a cylindrical specimen the confining pressure is equal to the radial stress and $\sigma_2 = \sigma_3$. The axial stress $\sigma_1$ on the other hand is varied to simulate the stress situation caused by the wheel loading (Magnusdottir, 1996).

### 2.5 Factors Affecting Resilient Response

In general, pavement analysis is concerned with using the principles of structural mechanics to establish relationship between pavement and subgrade material, the applied traffic loading, the thickness of pavement layers and granular material characteristics. It well known the granular pavement layer is a non-linear and time-dependent elastoplastic response under traffic loading. To deal with this non-linearity and to differentiate from the traditional elasticity theories, the resilient response of granular materials is usually defined by resilient modulus and Poisson's ratio (Lekarp, 2000).

For the road pavement design, it is important to consider how the resilient behaviour varies with changes in different influencing factors. The resilient behaviour of unbound granular materials is affected, with varying degrees of importance, by several factors as described below.

#### 2.5.1 Effect of Stress

The level of stress is a factor that has the most significant impact on resilient properties of granular materials. The resilient modulus is increased considerably with an increase in confining pressure and sum of principal stresses and decrease slightly with increasing repeated deviator stress under constant confinement.

The Poisson's ratio of unbound granular materials is influenced by the state of applied stresses and increases with increasing deviator stress and decreasing confining pressure. In laboratory triaxial testing, both constant confining pressure and variable confining pressure are used. From these two types of test, higher values of resilient modulus and Poisson's ratio computed from constant confining pressure and larger lateral deformations compared the results obtained from variable confining pressure. The stress level is important factors affecting to development the permanent deformation in granular material. The deformation in granular materials is principally governed by stress ratio consisting of both deviator and confining stresses. The axial permanent strain is directly related to deviator stress and inversely related to confining pressure (Lekarp, 2000).

### 2.5.2 Effect of Density

The resilient modulus generally increase with increasing density. The number of particle contacts per particle increases greatly with increased density resulting from additional compaction of the particulate system. The deformation in particle contacts decreases and the resilient modulus increases. The effect of density to be greater for partially crushed than for fully crushed aggregates. The resilient modulus was increase with relative density for the partially crushed aggregate tested, whereas it remained almost unchanged when the aggregate was fully crushed and density decreased as the fines content of the granular material increased (Lekarp, 2000).

The density of granular material was effect at high stress levels, which the resilient modulus is not very density-sensitive at above the optimum value. The level of density also seems to have some influence on Poisson's ratio to be small, with no consistent variation.

### 2.5.3 Effect of Grading

Granular materials consist of a large number of particles, normally of different sizes. The gradation of granular material was significant effect on the material stiffness. The resilient modulus has been increase with increasing maximum particle size and decrease with increasing fine increases. For the granular materials with same amount of fines and similar shape of grain size distribution, the resilient modulus has been increase with increasing maximum particle size.

The Particle size distribution or grading of granular materials seems to have some influence on material stiffness. The behaviour of crush granular material only slightly stiffer than well-graded aggregates, when moisture is introduced, the effect of grading can be significant, increased, because this material can hold water in the pores. They can also achieve higher densities than uniformly graded material because the small grains fill the voids between the larger particles and effect to weight of mass (Lekarp, 2000).

The grading has an indirect effect on the resilient behaviour of unbound aggregates by controlling the impact of moisture and density. For the variation in Poisson's ratio, increase the amount of fine aggregates has reduction the values.



### 2.5.4 Effect of Moisture Content

The presence of an adequate amount of water has positive influence on the strength and stiffness of unbound granular materials. The moisture content of most granular materials has been found to affect the resilient response characteristic of the material in both laboratory and in situ conditions. The resilient response of dry and most partially saturated granular materials is similar, but as complete saturation is approached and the resilient behaviour was affected.

The presence of moisture content in an aggregate assembly has some lubricating effect on particles and increases the deformation in aggregate with a consequences reduction of the resilient modulus. The effect of moisture content on the resilient modulus behaviour of unbound aggregates is significant in well-graded materials with high proportion of fines. This is because water is more readily in the pore of such materials, whereas uniformly graded materials allow water to drain freely fines (Lekarp, 2000).

Saturation of unbound granular materials also affects the resilient Poisson's ratio, which is reduced as the degree of saturation increases based on total or effective stresses analysis.

### 2.5.5 Effect of Number of Load Applications

The stress has some impacts on the resilient behaviour of granular materials. The stress effect is appearing as consequence of progressive densification and particle rearrangement under repeated application of stress. The granular material well-graded-crushed with same compacted density in a dry state was subjected to stress effects under repeated loading, but in the resilient response tests, the effect is reduce with preloading a few cycles of the current loading regime and avoiding high stress ratios (Lekarp, 2000).

The number of load cycles is one of the most important factors to consider in the analysis of the behaviour materials and increasing permanent deformation in material under repeated loading. Each load application contributes a small increment to the accumulation of strain. The resilient modulus increase as the number of load repetitions increases, partly because of loss the moisture from the specimen during testing. The resilient modulus was obtained from the repeated load test on the granular material and the value is virtually similar after 50-100 load repetitions as after 25,000 repetitions (Lekarp, 2000).

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