UNIVERSITI PUTRA MALAYSIA

DENSITY MEASUREMENT OF COMPACTED ASPHALT MIXTURES USING NON-DESTRUCTIVE GROUND PENETRATING RADAR

MARDENI BIN ROSLEE

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By

MARDENI BIN ROSLEE

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2009

Specially dedicated to my beloved:

Father, Mother,

Brother, Sisters,

Wife and Family,

and Friends.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DENSITY MEASUREMENT OF COMPACTED ASPHALT MIXTURES USING NON-DESTRUCTIVE GROUND PENETRATING RADAR

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Chairman : Raja Syamsul Azmir bin Raja Abdullah, PhD

Faculty : Engineering

This thesis describes the development of Ground Penetrating Radar (GPR) system based on the electromagnetic wave reflection to determine the density of road pavement**.** The proposed method is simple, fast, non-destructive and within an acceptable accuracy of road pavement density. The theoretical analysis based on the three existing GPR Mixture Model (GMM) methods has been improved to produce the most optimized function to be incorporated within the proposed GPR system. The study involves three main procedures which are theoretical analysis, laboratory scale experimentation and reliability analysis. From these studies, the Lichtenecker Mixture Model is found to be the most accurate function compared to the other models like Nelson and Landau due to the smallest mean error between the prediction and the experimental result. During the laboratory experimentation, an engineering GPR prototype has been developed and used to measure the road pavement density of the road pavement slab sample. The GPR

system consists of the transmitter which is signal generator as a microwave source, horn antenna for transmitting and receiving the signal, directional coupler with an adapter and spectrum analyzer to analyze the received signal. Nine road pavement slabs of middle boundary and ten slabs of upper and lower boundary of Hot Mix Asphalt (HMA) gradation were developed and tested at four different frequencies within the range of 1.7-2.6 GHz. The predicted signal attenuation from the theoretical analysis is compared to the signal attenuation measured from the laboratory experimentation. The comparison produces the relative error between these two results and it is used in the optimization process. The finding from the optimization process suggested that three additional constant parameters which are Volume factor, Permittivity factor and Attenuation factor need to be included to improve the existing GMM model. A field test had been conducted as an outdoor reliability analysis to validate the optimized GMM model. From the field test, it shows that the proposed GPR system works well with an error range from 3.37 % to 4.72 % for nine locations. Finally, a complete GPR system has been developed based on the optimized GMM attenuation curve to predict the density of a real road pavement.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGUKURAN KETUMPATAN CAMPURAN PADAT ASPAL MENGGUNAKAN PENEMBUSAN RADAR KE BUMI TANPA MUSNAH

Oleh

MARDENI BIN ROSLEE

April 2009

Pengerusi : Raja Syamsul Azmir Bin Raja Abdullah, PhD

Fakulti : Kejuruteraan

Tesis ini memperihalkan tentang pembinaan sistem penembusan radar ke bumi (GPR) berasaskan pantulan gelombang elektromagnetik untuk menentukan ketumpatan turapan jalan raya. Teknik yang dicadangkan ini adalah ringkas, cepat, tanpa musnah dan mempunyai ketepatan yang boleh diterima pakai untuk menentukan ketumpatan turapan jalan raya. Analisis teori yang berasaskan pada kaedah tiga model campuran GPR (GMM) yang sedia ada telah dipertingkatkan untuk menghasilkan fungsi pengoptimuman yang terbaik untuk digabungkan di dalam sistem GPR yang dicadangkan tersebut. Kajian ini melibatkan tiga prosedur utama iaitu analisis teori, eksperimen berkala makmal dan analysis keyakinan. Berasaskan pada kajian ini, Model campuran Lichtenecker didapati sebagai fungsi ketepatan yang terbaik dibandingkan dengan model-model yang lain seperti Nelson dan Landau disebabkan oleh min ralat

yang terkecil di antara keputusan eksperimen dan peramalan yang telah dibuat. Pada bahagian eksperimen makmal, prototaip GPR kejuruteraan telah dibina yang dapat digunakan untuk mengukur ketumpatan turapan jalan raya pada sampel kepingan turapan jalan raya. Sistem GPR terdiri daripada bahagian pemancar iaitu penjana isyarat sebagai punca gelombang mikro, antena hon sebagai pemancar dan penerima isyarat, pengawal gelombang dua arah dengan alat pengubahsuai dan penganalisis spektrum sebagai alat untuk menganalisis isyarat yang diterima. Sebanyak sembilan sampel kepingan turapan jalan raya jenis gradasi sempadan pertengahan dan sepuluh kepingan jenis atasan dan bawahan jenis HMA telah dibina dan percubaan pada empat frekuensi berlainan di dalam julat 1.7-2.6 GHz telah dilakukan. Nilai ramalan pengecilan kuasa gelombang yang berasaskan pada analisis teori telah dibandingkan dengan nilai pengukuran pengecilan daripada eksperimen di makmal. Perbandingan tersebut telah menghasilkan ralat relatif di antara dua keputusan ini dan ianya digunakan di dalam proses pengoptimuman. Penemuan berasaskan pada proses pengoptimuman mencadangkan bahawa tiga parameter tambahan iaitu faktor isipadu, faktor ketelusan dan faktor pengecilan perlu ditambah untuk memperbaiki model GMM tersebut. Analisis keyakinan pada kerja lapangan telah dilakukan dengan tujuan untuk menguji model GPR yang telah diperbaiki tersebut. Berdasarkan pada kerja lapangan, ianya menunjukkan bahawa sistem GPR yang telah dicadangkan tersebut dipercayai dapat digunakan sebaiknya dan memberikan nilai ralat daripada 3.37 % hingga 4.72 % terhadap sembilan lokasi kajian. Pada akhirnya, sistem GPR yang lengkap telah dibina dan dapat digunakan untuk menganggarkan nilai ketumpatan turapan jalan raya sebenar.

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I certify that an Examination Committee has met on 7 April 2009 to conduct the final examination of Mardeni bin Roslee on his thesis entitled "Density Measurement of Compacted Asphalt Mixtures using Non-Destructive Ground Penetrating Radar" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommended that the student be awarded the Doctor of Philosohpy.

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Date: 08 June 2009

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MARDENI BIN ROSLEE

Date: 28 April 2009

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5. GROUND PENETRATING RADAR MEASUREMENT RESULT

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACW	Asphalt Concrete Wearing
CW	Continuous Wave
EM	Electromagnetic
FRA	Federal Railroad Administration
FWD	Falling Weight Deflectometer
GPR	Ground Penetrating Radar
HMA	Hot Mix Asphalt
HMAC	Hot Mix Asphalt Concrete
JKR	Jabatan Kerja Raya
MATLAB	Matrix Laboratory
MNDT	Microwave Non-Destructive Technique
NCHRP	National Cooperative Highway Research Program
NDE	Non-Destructive Evaluation
OAC	Optimum Asphalt Content
PDF	Probability Density Function
PMS	Pavement Management System
PWD	Public Works Department
RAIRS	Railway Accident Incident Reporting Systems
SFR	Swiss Federal Railways
TE	Transverse Electric

TEM	Transverse Electromagnetic Modes
TDP	Timbalan Dekan Penyelidikan
TDR	Time Domain Reflectometry
TM	Transverse Magnetic
TMD	Theoretical Maximum Density
UPM	Universiti Putra Malaysia
VEE	Visual Engineering Environment
A	Attenuation
∂	Sensitivity
d	Density of road pavement
m	Mass of road pavement
v	Volume of road pavement
t	Road pavement slab thickness
D	Diameter of core sample
P_i	Received power
P_o	Transmit power
α	Attenuation constant
ε^*	Complex permittivity
ε'	Dielectric constant (or real part of permittivity)
ε''	Loss factor (or imaginary part of permittivity)
π	pi
E	Electric field intensity
H	Magnetic field intensity
ε	Permittivity