INTEGRATING SEISMIC REFLECTION METHOD WITH ARTIFICIAL NEURAL NETWORK PROCESSING FOR ASPHALT PAVEMENT THICKNESS EVALUATION

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In Memory of Hadj Belkacem Remmani

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ABSTRACT

Geophysical methods play a crucial role in the field of civil engineering, particularly in assessing pavement thickness. While conventional methods have been utilised in the past and are still in use today, there is a constant pursuit for better solutions. This study focuses on the seismic reflection method as a non-destructive quality assurance technique for measuring pavement thickness. preliminary experimentation is executed within a controlled laboratory milieu, encompassing a comprehensive evaluation and refinement process for diverse seismic sources and receivers. This endeavor aims to attain an optimized configuration conducive to high-frequency acquisition. An automated data processing method is developed using a feed-forward multi-layered neural network implemented in MATLAB. A user-friendly graphical user interface is also constructed to enhance and facilitate data processing and result calculations. The developed method is successfully tested on several asphalt pavement sites within the university campus, yielding an average measurement accuracy of 93%. Furthermore, the established method's findings and accuracy are validated by comparing them with both destructive and non-destructive conventional pavement thickness measurement methods. The outcome of this research is an innovative approach that overcomes the limitations of destructive conventional methods, providing a non-destructive solution for pavement thickness measurement. The study contributes to advancing the field of civil engineering by introducing a reliable and accurate technique for quality control and quality assurance in pavement construction and maintenance projects.

ABSTRAK

Kaedah geofizik memainkan peranan penting dalam bidang kejuruteraan awam, terutamanya dalam menilai ketebalan turapan. Walaupun kaedah konvensional telah digunakan pada masa lalu dan masih digunakan hari ini, terdapat usaha berterusan untuk penyelesaian yang lebih baik. Kajian ini memfokuskan kepada kaedah pantulan seismik sebagai teknik jaminan kualiti tidak merosakkan untuk mengukur ketebalan turapan. eksperimen awal dilaksanakan dalam persekitaran makmal terkawal, merangkumi penilaian komprehensif dan proses penghalusan untuk sumber dan penerima seismik yang pelbagai. Usaha ini bertujuan untuk mencapai konfigurasi yang dioptimumkan yang kondusif untuk pemerolehan frekuensi tinggi. Kaedah pemprosesan data automatik dibangunkan menggunakan rangkaian saraf berbilang lapisan ke hadapan suapan yang dilaksanakan dalam MATLAB. Antara muka pengguna grafik yang mesra pengguna juga dibina untuk meningkatkan dan memudahkan pemprosesan data dan pengiraan keputusan. Kaedah yang dibangunkan ini berjaya diuji di beberapa tapak turapan asfalt dalam kampus universiti, menghasilkan ketepatan pengukuran purata 93%. Tambahan pula, penemuan dan ketepatan kaedah yang telah ditetapkan disahkan dengan membandingkannya dengan kaedah pengukuran ketebalan turapan konvensional yang merosakkan dan tidak merosakkan. Hasil daripada penyelidikan ini adalah pendekatan inovatif yang mengatasi batasan kaedah konvensional yang merosakkan, menyediakan penyelesaian yang tidak merosakkan untuk pengukuran ketebalan turapan. Kajian ini menyumbang kepada memajukan bidang kejuruteraan awam dengan memperkenalkan teknik yang boleh dipercayai dan tepat untuk kawalan kualiti dan jaminan kualiti dalam projek pembinaan dan penyelenggaraan turapan.

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LIST OF SYMBOLS AND ABBREVIATIONS

MLNN	-	Multi layered Neural Network
CDP	-	Common Depth Point
FFT	-	Fast Fourier Transform
FWD	-	Falling Weight Deflectometer
GPR	-	Ground-Penetrating Radar
GUI	-	Graphical User Interface
h	-	Thickness
IE	-	Impact Echo
MASW	-	Multichannel Analysis of Surface Waves
NDT	-	Non-Destructive Testing
P wave	-	Pressure Waves
QA	-	Quality Insurance
QC	-	Quality Control
S wave	-	Surface Waves
SASW	-	Spectral Analysis of Surface Waves
SNR	-	Signal to Noise Ratio
USW	-	Ultrasonic Surface Wave
UTHM	-	Universiti Tun Hussein Onn Malaysia
Vp	-	Pressure wave Velocity

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CHAPTER 1

INTRODUCTION

1.1 Background

Pavement is designed concerning both the thickness and strength as certain key elements, including durability, smoothness, surface texture and flexibility. The purpose of road paving is generally to build a sturdy and lasting road by choosing suitable materials and dimensions and implementing quality control measures so that the flexible pavement layer can protect the subgrade from the impact caused by traffic loads. Asphalt pavement thickness is a significant factor determining the quality control and quality assurance (QC/QA) of a newly-constructed pavement since deficiencies in thickness can negatively effect on-road life. Performance modelling has allowed for determining the relationships between pavement thickness and its lifespan. To implement the pavement thickness parameter as a measure for quality control and quality assurance (QC/QA), it is necessary to have an accurate and reliable measurement method. Conventional methods like cores are accurate but more time-consuming and damaging to the pavement system. Conventional methods also represent a small portion of the overall thickness. Therefore, developing and employing effective non-traditional quick, and non-destructive methods that can generate more accurate results is crucial.

Geophysical investigative methods and civil engineering are strongly interconnected, and these methods have been exercised and applied to various kinds of civil engineering projects for decades. For example, geophysical methods help evaluate the complex and changing subsurface as a foundation for huge dams, bridges, highways, and roadways. In addition, many geophysical techniques are applied for structural investigations in several civil engineering spheres. These methods are also widely recognised by experts and engineers as practical tools to enhance the interior imaging quality of the structures and detect changes in the concrete.

The current condition of quality control and quality assurance (QC/QA) operations of the superstructure and infrastructure projects focused intensely on the constructability and enduringness of the materials. To implement effective QC/QA methods, performance-based designs and warranted structures, the current processes should be remodelled to gain continuity in design, tests, and final construction. A broad QC/QA practice should be integrated with several interrelated things, such as a correlation between effective practices of QC/QA and design parameters. To a significant extent, pre-construction laboratory tests to determine the suitability of the material and QC/QA procedure must achieve the required levels (Celaya, Shokouhi, and Nazarian, 2007).

Developing the most durable pavement layer has become a focal point for highway agencies in the present century. Several conventional methods for engineering and construction have performed well over the years. They are considered very suitable for pavement structures. However, their use has certain drawbacks, such as high energy usage, environmental disgrace, increase in carbon level, low-quality results for mixed production, health, and safety threats, oxidative hardening, limited time for construction, and weather vulnerabilities (Meghna and Puppanna, 2018). Monitoring of crucial parameters of pavement layer operations has become more critical during the last few decades, and there are specific trends in civil engineering and especially in road construction in practice. These trends provide authentic insights about paving operations to contractors and construction companies to improve pavement construction (Landi *et al.*, 2020). Monitoring different parameters while road construction could help paint a clearer picture for engineers of new insights regarding factors such as pavement material and age. Knowing this helps contractors who deal with construction daily because this information can lead to more efficient pavement operations.

Asphalt pavement failure and degradation are the most common occurrences, especially after construction. Therefore, restoring, maintaining, and monitoring pavements seated upon sub-soil layers is highly important (Woods and Adeox, 2002). A continuous stretch of asphalt should be laid for a smooth and comfortable drive, but a lack of quality control and quality assurance (QC/QA) in the road construction could produce ruts, depressions, cracks, and bulges leading to road failure (Aigbedion, 2007). The outdated drainage system, low-quality construction materials, poor design, and usage alongside geological aspects are some of the crucial factors of road failure (Momoh, Akintorinwa, and Olorunfemi, 2008).

The quality of asphalt pavement layers is entirely dependent on several factors. Layer thickness is a crucial factor that plays a role in the quality control of asphalt pavement. Although layer thickness is a quality parameter that can be monitored regularly, contractors cannot constantly monitor the layer thickness during the paving process. With this in mind, asphalt paving companies have taken it upon themselves to develop more sophisticated technology that works with paved roads and helps ensure that pavement layers meet specific quality standards, allowing them to be more reliable.

Contractors are often plagued with inconsistent layer thickness. This inconsistency adversely affects the quality of paving operations because it can cause ruts to form, which require costly repairs. One crucial step to overcome this problem is to seek technologies that measure asphalt's layer thickness during paving procedures. Furthermore, one should evaluate these technologies based on their ability to provide real-time data about the layer thickness of roadways while paved. By utilising this information, contractors would be better able to ensure the quality of the asphalt layer thickness.

Pavements can also be distinguished by their structure; they could be flexible, rigid, or semi-rigid. In rigid types of pavements, the surface layer is usually made of a reinforced concrete slab that got its foundation over a thin concrete layer. Flexible pavements have an asphalt layer as their surface layer. Determining the thickness of pavement layers, pavement properties, and their behaviours describes the differences in their structure and deformation in flexible pavement structures.

Highly accurate non-destructive testing (NDT) methods are often preferentially used over time-consuming, unsafe, and costly conventional destructive methods. NDT methods are considered a more accurate and practical approach to overcoming technological deficiencies in the pavement thickness measurement process and ensuring the quality inspection of pavement structures (Capozzoli and Rizzo, 2017). Portable non-destructive testing (NDT) equipment is fixed to the frame of an automobile and allows for quick and easy inspections. The systems used throughout various industries even help save time and money as opposed to conventional methods.

Non-destructive testing methods are capable of gathering and processing data quickly and efficiently. Various standard methods used to test the quality of asphalt include penetration, shear, and measurement. However, one must choose opt a non-destructive technology capable of testing without destroying the pavement layers. Here it allows for an accurate thickness measurement without damage to the inspected pavement or its surface. It also has higher application rates than conventional methods, which is one of the reasons NDT methods are considered highly applicable and adaptable. Pavement layer thickness measurement is significant in recent civil engineering and infrastructural economics industry trends. Modern NDT technology assists in improving this process by handling real-time data and processing it at a time when it is necessary regardless of location and thereby achieving better outcomes and lesser costs due to its quality promptly with cost-effective techniques.

Even though incorporated methods are considered most appropriate for structural evaluation and diagnosis, the seismic methods are exclusively used in situ and lab testing to characterise materials, determine the extent of decay, develop conservation procedures, and evaluate the performance of the consolidated materials. Seismic P-Wave and S-Wave testing can produce valuable data for pavement layer properties and characterisation of the materials. These tests can be conducted during or after pavement construction.

Through this development, authentic insights can be achieved for further research related to project management needs. In addition, this achievement will enable them to establish which parameters have been affected most in lacking pavement system measurements in future pavement perfection steps so that they can develop their processes for more efficient measures.

1.2 Problem statement

Accurate measurement of asphalt pavement thickness is crucial for ensuring the long-term durability and quality of roads. Conventional methods, such as coring, are destructive and can lead to unsafe conditions and reduced measurement density. Non-destructive testing methods, while more efficient, still have limitations, including interference from materials and sensitivity to certain substances like clay and salt (Colagrande, Ranalli, and Tallini, 2020). The existing methods for examining pavement quality suffer from limitations in terms of rapid results, variations in material samples, and constraints related to the structure, cost, and size of the construction.

The research problem addressed in this study is the need for an effective and reliable method for non-destructive measurement of asphalt pavement thickness that overcomes the limitations of conventional and existing non-destructive techniques. The proposed method aims to utilise seismic reflection technology, which has the potential to accurately map paved surfaces by capitalising on the varying acoustic impedance between the asphalt pavement layer and the underlying soil.

By developing and implementing a seismic reflection-based approach, this research aims to address the challenges associated with destructive coring methods and the limitations of existing non-destructive testing techniques. The proposed method has the capability to provide accurate and efficient measurements of asphalt pavement thickness, allowing for timely optimization of layer thickness and enhanced quality control and quality assurance in road construction and maintenance projects.

The focus of this research is to develop an innovative solution that improves the accuracy and reliability of pavement thickness measurements, enhances the overall integrity of roads, and contributes to the advancement of civil engineering practices in the field of pavement management and construction.

1.3 Aim & objectives of the research

The study aims to develop an acoustical-based system for attaining and utilising data to measure the pavement layer thickness using an NDT approach i.e., the seismic reflection. The following objectives are set to meet the aim of this study:

i. To establish an equipment setup to overcome the seismic reflection limitations on shallow depth and high frequencies acquisitions.

ii. To develop an automated data processing approach integrated with a friendly user interface to limit the experienced operator's requirement to use the reflection technique on pavement thickness measurement.

iii. To assess the seismic reflection technique in measuring the shallow profiling and identifying pavement layer thickness.

iv. To validate the seismic reflection method with other relevant methods.

1.4 Originality of the research

The originalities of this research are the following:

i. A new non-destructive approach for pavement thickness measurement using the seismic reflection is introduced.
ii. A source-receiver array optimisation for wave isolation is introduced in this study. Alongside with the equipment assemblage.
iii. A Multi-layered Neural Network is developed as a part of this research for automatic and instant seismic time domain reflection data processing.
iv. This research developed a graphical user interface for results presentation without mastering the MATLAB scrip language.

1.5 Scope of the study

To achieve the aims and objectives of this study, the measurement of asphalt pavement thickness is carried out using the seismic reflections method. Validating and assessing the method's accuracy, the conventional destructive coring method with the conventional non-destructive impact echo on different field sites of different pavement structures is established.

One of the advantages of using the seismic reflection technique in the time domain is the absence of the need to perform any pre-test preparations, calibration, separated external testing or assumptions. In addition, the seismic reflection method can evaluate and measure pavement thickness directly.

The scope of this research includes the measurements of pavement thickness, which can be evaluated by implementing the reflection-based system in the field. Therefore, a systematic approach was developed to define the capabilities of this method in evaluating pavement layers' thickness. Therefore, the approach of this study is limited to the following steps:

a. In situ testing procedures combined with lab tests are conducted to assess the thickness of the asphalt layer.

b. The pavement measurements are done in the university campus only. Thus, the measurements are limited to the tested sites.

c. The method has been validated up to 15 cm targeted depth thus the technique applicability depth range is set accordingly.

d. The calculated the reflection waves' arrival time using a feed-forward multi layered neural network prediction model integrated with the graphical user interface in MATLAB software.

e. The impact echo method and coring tests are used to authenticate and evaluate the seismic reflection as an asphalt pavement thickness measurement tool.

f. The implementation of the concrete slab testing is for the objective of observing the behaviour of the seismic reflection method in varied situations and materials.

1.6 Significance of the study

Transportation infrastructure, including asphalt pavement, plays a critical role in facilitating efficient movement and communication within society. The serviceability of roads is paramount for industrial growth, commerce, and the transportation of goods (Bellanova, Calamita, Catapano et al., 2020). A fundamental aspect of road management is the accurate measurement of pavement layer thickness, as it significantly contributes to the overall quality and performance of the pavement structure (Leng and Al-Qadi, 2014). The characterization of pavement structure, including the thickness of the asphalt layer, holds great importance in enhancing the integrity of roads and benefiting various engineering projects in the region.

In this context, non-destructive testing (NDT) methods have proven to be invaluable in the measurement of pavement thickness and the evaluation of remaining pavement lifespan (Grégoire and Van Geem, 2013). Integrating NDT measurements into the pavement construction process allows for informed decisions regarding structural repairs or overlays. The non-invasive nature of NDT techniques offers notable advantages over conventional methods, saving both time and costs for employers (Liu, Liu, Zhang et al., 2018).

Despite the benefits of NDT methods, there exist gaps and challenges that need to be addressed. The non-uniformity and instability of asphalt pavement layer thickness can compromise the functionality and longevity of roads (Muller, 2014). Current NDT methods used for shallow investigations have limitations in terms of data acquisition, accuracy, and overcoming specific challenges associated with the asphalt layer.

Seismic reflection technology emerges as a promising solution to overcome these limitations and accurately measure pavement thickness without causing damage to the surface layer. While seismic reflection has demonstrated success in shallow soil investigations, its application in pavement research is an area that requires further exploration and development (Loizos and Plati, 2007).

Hence, the primary objective of this study is to develop and implement an effective and accurate pavement thickness measurement tool utilising the seismic

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APPENDIX A

LIST OF PUBLICATION

- Shallow reflection method for pavement thickness measurement (**SA Remmani**, A Madun, H Benmalek, 2020, Journal of Fundamental and Applied Sciences 12 (1S), 324-334) **Published journal article.**

- Asphalt Pavement Thickness Measurement Using the Seismic Reflection Technique (**SA Remmani**, A Madun, NHBM Kamaruddin, 2020, International Journal of Scientific & Technology Research 9 (06), 527-531) **Published journal article**

- Numerical Seismic Approach for Pavement Investigation (A Madun, NHBM Kamaruddin, **SA Remmani**, 2020, International Journal of Scientific and Technology Research 9 (04), 1894-1900) **Published journal article Scopus Q3**

- Artificial Neural Network in Seismic Reflection Method for Measuring Asphalt Pavement Thickness (**SA Remmani**, A Madun, NHBM Kamaruddin, O Laghouiter, A Belouaar, 2023, international journal of sustainable construction engineering and technology) **Published journal article Scopus Q4**

- Artificial Neural Network for Seismic Signal Processing and Predictions, ID: CP918, No. Application: LY2023J01251, **Type of IP: Copyright** Role: Owner/principal researcher

APPENDIX D

VITA

The author was born in 26 nov 1992 in Timimoun, Algeria, currently pursuing a PhD in Civil Engineering at UTHM. He holds a Master's and Bachelor's Degree in Civil Engineering from Djillali Liabes University of Sidi bel Abbes in 2016 and 2014 respectively. His research centers around integrating seismic reflection methods with artificial neural network processing for pavement thickness evaluation. Mr. Remmani has co-authored four papers in nondestructive testing research areas where has secured intellectual property rights for his work. Sid Ahmed's professional background encompasses roles as an onsite technician for ETBH from 2014 to 2018, followed by a position as a Civil Engineer at TCE REMMANI starting in 2020. His responsibilities include overseeing rehabilitation projects and serving as a quality inspector and head of projects, specializing in earthen and concrete buildings. Sid Ahmed Remmani's linguistic proficiency includes being a native speaker of Arabic, complemented by an excellent command of spoken and written English, a good command of spoken and written French, and an average proficiency in spoken Bahasa Melayu.