PSZ 19:16 (Pind. 1/07)

UNIVERSITI TEKNOLOGI MALAYSIA

DECLARATION OF THESIS

Author's full name : SOPHIA C. ALIH

Date of birth : 12 May 1980

Title : THE APPLICATION OF ARTIFICIAL NEURAL NETWORK IN NONDESTRUCTIVE TESTING FOR CONCRETE BRIDGE INSPECTION RATING SYSTEM

Academic Session: 2007/2008

I declare that this thesis is classified as:

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
√	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)*
☐	**OPEN ACCESS**	I agree that my thesis to be published as online open access (full text)

I acknowledged that Universiti Teknologi Malaysia reserves the right as follows:

1. The thesis is the property of Universiti Teknologi Malaysia.
2. The Library of Universiti Teknologi Malaysia has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

SIGNATURE	**SIGNATURE OF SUPERVISOR**
800512-12-5620	Assoc. Prof. Dr. Azlan Bin Adnan
(NEW IC NO. /~~PASSPORT NO.~~)	**NAME OF SUPERVISOR**
Date :	Date :

NOTES : * If the thesis is CONFIDENTAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

29 October 2007

Librarian
Perpustakaan Sultanah Zanariah
UTM, Skudai
Johor

Sir,

CLASSIFICATION OF THESIS AS RESTRICTED

THE APPLICATION OF ARTIFICIAL NEURAL NETWORK IN NONDESTRUCTIVE TESTING FOR CONCRETE BRIDGE INSPECTION RATING SYSTEM: SOPHIA C. ALIH

Please be informed that the above mentioned thesis entitled ***" THE APPLICATION OF ARTIFICIAL NEURAL NETWORK IN NONDESTRUCTIVE TESTING FOR CONCRETE BRIDGE INSPECTION RATING SYSTEM "*** be classified as RESTRICTED for a period of three (3) years from the date of this letter. The reasons for this classification are

(i) Bridge inventory data, and inspection report data used in this study are confidential and restricted by the Public Works Department of Malaysia.

(ii) The nondestructive testing results of the bridges in this thesis are confidential.

Thank you.

Sincerely yours,

ASSOC. PROF. DR. AZLAN BIN ADNAN,
FACULTY OF CIVIL ENGINEERING,
UNIVERSITI TEKNOLOGI MALAYSIA,
SKUDAI JOHOR.
(07-5591503)

"We hereby declare that we have read this thesis and in our opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Master of Engineering (Structures)"

Signature : --

Name of Supervisor I : Assoc. Prof. Dr. Azlan Adnan

Date : --

Signature : --

Name of Supervisor II : Prof. Ir. Dr. Abd. Karim Mirasa

Date : --

Signature : --

Name of Supervisor III : --

Date : --

BAHAGIAN A – Pengesahan Kerjasama*

Adalah disahkan bahwa projek penyelidikan tesis ini telah dilaksanakan melalui kerjasama antara

…………………………………dengan…………………………………

Disahkan oleh:

Tandatangan : ………………………………………… Tarikh ………………….

Nama : …………………………………………..

Jawatan : …………………………………………..

(Cap rasmi)

** Jika penyediaan tesis/projek melibatkan kerjasama.*

==

BAHAGIAN B – Untuk Kegunaan Pejabat Sekolah Pengajian Siswazah

Tesis ini telah diperiksa dan diakui oleh:

Nama dan Alamat Pemeriksa Luar : ..Ir. Dr Mohamad Ismail

Jabatan Kerja Raya

Cawangan Kuala Lumpur.

Nama dan Alamat Pemeriksa Dalam : ..Prof. Madya Ir. Dr. Wahid Omar.

Ir. Dr. Rosli Zin, Fakulti

Kejurutaraan Awam, UTM Skudai .

Nama Penyelia Lain (jika ada) : ..Prof. Ir. Dr. Abdul Karim Mirasa

Fakulti Kejuruteraan Awam...

UTM Skudai...

Disahkan oleh Penolong Pendaftar di SPS:

Tandatangan : .... Tarikh: ....

Nama : ....

THE APPLICATION OF ARTIFICIAL NEURAL NETWORK IN NONDESTRUCTIVE TESTING FOR CONCRETE BRIDGE INSPECTION RATING SYSTEM

SOPHIA C. ALIH

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Structures)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

OCTOBER 2007

I declare that this thesis entitled "*The Application of Artificial Neural Network in Nondestructive Testing for Concrete Bridge Inspection Rating System*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	
Name	:	SOPHIA C. ALIH
Date	:	29 October 2007

For my beloved Ayah and Ina

Abang Bik, Abang King

Soti, Joe, Ora, Mona,

Khaty, Su, Kikin,

Omas, Tatang

ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisors; Assoc. Prof. Dr. Azlan Bin Adnan, and Prof. Ir. Dr. Abdul Karim Bin Mirasa from the Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor for their continuous support and supervision during the years of my study. It is their brilliant ideas and expertise that led this study to its successful outcome.

Special thanks to the staff of Bridge Unit, Public Works Department (Johor State Branch and district branches include Kota Tinggi, Mersing, Pontian, Segamat, Muar, Batu Pahat, Kluang, and Johor Bahru branch) for providing me the bridge data and supporting me during my field tests. Not forgetting the staff of Structural Laboratory, Faculty of Civil Engineering (Mr. Jamaludin, Roslee, Azam and Za'ba) for their willingness to join my field tests and valuable time they have spent. Their work and dedication to this study is very much appreciated for without it the objective of this study can not be fulfilled.

My appreciation also goes to Mr. Mohd. Rosman Bin Abd. Rahman for his care, thoughtfulness, and devoted involvement in this study. His continuous support gave me the strength to complete this study especially during the hard times. Also thanks to the SEER members; Kak Ana, Suhana, Kak Jati, Rozaina, Abang Hendry, Meldi, Lami, and En. Rosaidi for being my family and friends all these years.

ABSTRACT

The aim of this study is to determine the condition of bridges through nondestructive testing and to establish correlation between the visual inspection rating and the nondestructive testing results. Despite of their potential to be applied in bridge inspection, implementation of this method in routine inspection may be limited and it is not always readily available due to the problems that might occurred with the lack of experienced inspectors to conduct the test. Therefore, an intelligent rating system which combines both nondestructive test data and visual inspection rating has been developed to predict both ratings at any given time. Backpropagation algorithm with one hidden layer is used to develop the artificial neural network (ANN) and Borland C++ is used as the programming tool. In this study, 75 concrete bridges under the supervision of Public Works Department, PWD (Malaysia) were selected for the preliminary testing which includes the Rebound Hammer (RH) test, the Ultrasonic Pulse Velocity (UPV), and the electromagnetic cover meter. The visual rating shows 0-1 rating differences when compared to the RH ratings, in which the former tend to be much higher than the RH. However, UPV ratings are higher than the visual rating with an average difference of three ratings. The visual rating yields similar indication as RH since both approaches represent only the surface condition of the bridge. The UPV test represents the bridge condition better than RH although the indirect transmission of the results can be affected by the surface condition. Due to the higher speed and the minimum cost in conducting these tests, the rebound hammer, the UPV and the cover meter have been identified as having potential to be used as preliminary tests in evaluating the bridge condition. The ANN system developed in this study able to predict the condition rating between 70% and 90% accuracy. The linear correlation coefficient between actual rating and rating predicted by the network is between 0.6 and 0.9 indicating a strong relationship between these two values. This shows that the ANN is capable of producing accurate results. This intelligent system can help the authority to forecast bridge condition at any given time. Critical bridges can be short listed and prioritized for the allocation of maintenance budget. In general, findings from this study are useful to the PWD in monitoring the structural condition of existing bridges through the NDT method aided by the intelligent system developed in this study.

ABSTRAK

Matlamat kajian ini ialah untuk menentukan keadaan jambatan melalui ujian tanpa musnah dan seterusnya mendapatkan perhubungan antara hasil ujian ini dengan perkadaran yang dibuat secara visual. Walaupun mempunyai potensi untuk diaplikasikan dalam pemeriksaan jambatan, perlaksanaan kaedah ini dalam pemeriksaan berkala agak terhad dan kurang dipraktikkan disebabkan masalah yang mungkin timbul ekoran daripada kekurangan tenaga mahir untuk menjalankan ujian ini. Maka, satu sistem pengkadaran pintar yang menggabungkan data daripada ujian tanpa musnah dan pemeriksaan visual telah dibangunkan dalam kajian ini. Sistem ini membolehkan ramalan tentang kekuatan sesuatu struktur jambatan dibuat pada bila-bila masa. Algoritma perambatan belakang dengan satu lapisan tersembunyi telah digunakan untuk membangunkan sistem rangkaian saraf buatan (ANN) dengan menggunakan bahasa perisian C++. Dalam kajian ini, sebanyak 75 jambatan konkrit di bawah seliaan Jabatan Kerja Raya (JKR) Malaysia telah dipilih untuk pemeriksaan awal ujian tanpa musnah yang terdiri daripada ujian tukul pantul (RH), kelajuan denyut ultrabunyi (UPV), dan meter penutup (CM). Perkadaran visual menunjukkan perbezaan sebanyak 0-1 kadar berbanding RH, dimana perkadaran visual adalah lebih tinggi. Walau bagaimanapun, perkadaran UPV adalah lebih tinggi daripada perkadaran visual dengan perbezaan purata sebanyak tiga kadar. Perkadaran visual adalah sama dengan perkadaran RH memandangkan kedua-dua kaedah ini hanya mewakili permukaan struktur sahaja. Ujian UPV memberikan keadaan jambatan yang lebih baik daripada RH walaupun keputusan daripada penghantaran tak langsung boleh dipengaruhi oleh keadaan permukaan. Dengan kecepatan dan kos yang rendah, ujian tanpa musnah mempunyai potensi yang tinggi untuk mengkaji keadaan struktur pada peringkat awal. Sistem ANN yang dibangunkan dalam kajian ini boleh meramal kadar kondisi struktur diantara 70 dan 90 peratus ketepatan. Pekali perhubungan linear diantara kadar sebenar and kadar yang diramal oleh ANN adalah diantara 0.6 dan 0.9 dan ini menunjukkan hubungan adalah tinggi. Ini menunjukkan ANN berupaya menghasilkan keputusan yang tepat. Sistem pintar ini boleh membantu pihak berkuasa meramal kekuatan jambatan pada sesuatu masa dengan mudah. Jambatan yang kritikal boleh disenarai pendekkan dan diberi keutamaan dalam perancangan perbelanjaan. Sebagai kesimpulanya, hasil daripada kajian ini adalah amat berguna kepada JKR dalam proses penilaian keadaan struktur jambatan sedia ada melalui ujian tanpa musnah dengan bantuan sistem pintar yang telah dibangunkan.

TABLE OF CONTENTS

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 THEORETICAL BACKGROUND

CHAPTER 4 METHODOLOGY

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ANN	-	Artificial neural network
C_n	-	Calculated value
CM	-	Cover meter
d_n	-	Desired output
D	-	Actual value
E	-	Total squared error
H	-	Hidden layer
I	-	Normalized value
I_{ik}	-	Input of the k^{th} processing element from the i^{th} processing element
L	-	Path length between two transducers
MSE	-	Mean square error
NDT	-	Nondestructive testing
O	-	Output
PE	-	Probability of exceedance
PGA	-	Peak ground acceleration
PWD	-	Public Works Department
r	-	Linear correlation coefficient
R	-	Rebound number
$R_{c,s}$	-	Estimated cube strength
RH	-	Rebound hammer
RI	-	Relativity index
S_c	-	Crushing strength

t	-	Time taken by pulse to travel between two transducers
T_j	-	Internal threshold for j^{th} processing element
TR	-	Return period
UPV (D)	-	Ultrasonic pulse velocity for direct transmission
UPV (In)	-	Ultrasonic pulse velocity for indirect transmission
UPV	-	Ultrasonic pulse velocity
V, W	-	Connection weight
VI	-	Visual inspection
x	-	Nondestructive parameters
v	-	Pulse velocity
η	-	Learning rate
α	-	Momentum coefficient

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter will cover the overall introduction to this thesis. The importance of bridge inspection will be reviewed in general followed by current limitations and problems faced by the existing practice. The advantages of nondestructive testing method in overcoming the limitations and the potential of artificial neural network to be implemented in bridge inspection are then reviewed. These will lead to the problem statement and significance of conducting this study. The objectives and scope of work are then outlined. Next, the methodology used in this study will be discussed in general. Finally, the thesis organization will be reviewed. This covers every chapter in the thesis and their contents.

1.1 Background

Assessing the condition of a structure is necessary to determine its safety and reliability. Ideally, structural health monitoring should be similar to medical health monitoring of the body. In medical health monitoring, the life signs such as pulse and blood pressure give an overall indication of the overall health of the body. This is analogous to structure health monitoring, in which damage to the structure can be identified by measuring changes in the global properties of the structure. Once the body signs show an anomaly, we do a medical check-up to determine the cause of the anomaly. Analogously in structural health monitoring, nondestructive evaluation can be used to determine the nature of the damage.

Concrete bridges are exposed to numerous environmental loads and traffic loads which increase from time to time. These can cause a reduction in overall strength and lead to eventual failure of the bridge. Periodic bridge inspections are therefore necessary to assess the extension, implications, and current state of the deterioration process. Inspections not only help to prevent failure but also deliver information necessary for effective administration of the bridge network. Thus, the authority can further define priorities and establish programs to apply available resources to the most critical bridges.

Currently bridges are evaluated through visual observation during the annual inspection or detail inspection using nondestructive or semi-destructive testing if the bridges are reported to have defects (Malaysia, 2004). Visual inspections are commonly used nowadays. When bridge evaluation is conducted using this method, rating will be assigned to the bridge components by a responsible inspector. The major problem with visual inspection is the inherent variability that naturally occurs when subjective observations are converted to a numerical rating. Bridge evaluation based on this method may vary according to personal judgment. Thus, large uncertainties exist in the interpretation of inspection data.

Nondestructive evaluations are one of the techniques suggested by researchers to overcome the limitations faced by the existing rating system. This method has gained interests among researchers due to its ability in determining damages inside the structure that are not visible. Previous research show a good potential of nondestructive testing to be used in evaluating structural condition of existing structure. Thus several trials were carried out to correlate data from nondestructive testing with visual inspection in order to enhance the existing evaluation process.

Despite of all the advantages of using the nondestructive testing, this method is not always readily available and there may be problems due to the lack of experienced inspectors to conduct the test. Hence, the implementation of this method in routine inspection may be limited. The strong capability of artificial neural networks in predicting fuzzy data and the successful application of this approach in various fields sparks the idea of implementing ANN to predict bridge condition based on nondestructive testing data and visual inspection. In other words, nondestructive tests may not be necessarily conducted in each routine inspection; previous nondestructive testing results will be used to predict the condition rating of a bridge. It is hoped that this system will assist the current inspection process and thus lead to a more detail evaluation.

1.2 Problem Statement

Existing practice in evaluating bridge conditions through visual inspection has been identified to have few limitations. Despite of their role as the first step of any condition assessment procedure, this type of evaluation is subjected to large uncertainties and depends primarily on a personal judgment of the responsible inspector. Ratings assigned to the bridge component are subjective and may vary according to the visual observation. Due to these limitations, numbers of research have been conducted to improve assessment made using visual inspection.

In recent years, researchers and industrial practitioners has turn to nondestructive testing (NDT) method to evaluate structures due to the ability of this method in determining non-visible defects inside the structure that is not possible to be evaluated through visual inspection. Therefore, the NDT method has been chosen in this research to support evaluation made in the existing practice. However, despite of their advantages, this method is not always readily available and there may be problems due to the lack of experienced inspectors to conduct the test. Hence, the implementation of this method in routine inspection may be limited.

If the NDT results can be predicted, the bridge condition can still be assessed without even conducting the test during inspection. The strong capability of artificial neural networks (ANN) in predicting fuzzy data and the successful application of this approach in various fields gives the idea of implementing ANN to predict bridge condition based on previous inspection data. If this approach is successful, there will be less works that need to be done during inspection and yet the evaluation is still thorough. This will benefit more people that are involved in bridge inspection especially the bridge authority. This system can help the authority to forecast bridge condition at any given time. Critical bridges can be short listed and prioritized for the allocation of maintenance budget.

1.3 Objectives

This study is conducted to comply with the following objectives:

i) To produce detail evaluation on selected bridges using nondestructive testing (NDT) method
ii) To determine the correlation between NDT results and visual inspection (VI) ratings
iii) To develop Artificial Neural Network (ANN) algorithm for the prediction of NDT results and VI ratings
iv) To determine the correlation between NDT results and VI ratings from field test (manual process) and ANN

1.4 Scope of Work

This study will cover two main aspects; conducting bridge evaluation through NDT and programming the ANN to predict the ratings. Scopes of works for this study are listed below:

i) Designing new forms to be used for NDT during bridge evaluation. Four new forms are prepared for general information and sketches, rebound hammer test, ultrasonic pulse velocity (UPV) test, and cover meter.

ii) Conducting NDT on selected bridges. Public Works Department, PWD bridges along the Federal Roads (Johor State) are selected. Inspection are limited to concrete bridges. Three NDT methods are applied including the rebound hammer test, UPV test, and electromagnetic cover meter

iii) Analyzing inventory data and visual inspection report for the selected bridges. These data will be collected from PWD in 8 districts in Johor state. The inspection report for the year 2005 will be used for analysis

iv) Designing the best ANN topology to predict VI ratings and concrete strength through NDT results. Backpropagation network with one hidden layer will be used to train the network. Borland C++ will be used as the programming tool.

1.5 Methodology

This study can be represented in five phases as shown in Figure 1.1; planning phase, site survey phase, evaluation phase, programming phase, and finally the conclusion. Each phase applied different types of methodologies. In the early stage of this study; planning phase, preliminary surveys are conducted to identify the significant of doing this research in civil engineering area particularly in bridge engineering. Literature studies are carried out in various fields especially in bridge inspection, NDT and ANN.

After completing the planning phase and all the standard procedures, site survey starts to take place. This phase begins with site visits to every district in Johor state including Johor Bahru, Pontian, Kluang, Batu Pahat, Muar, Kota Tinggi, Mersing, and Segamat to select the bridges to be inspected. For this purpose, all bridges in the districts are visited with the help of the PWD workers to gather information on the bridge structures and their locations. Inventory data and visual inspection report for the selected bridges are then taken from the PWD office. These information are analyzed prior to the inspection itself. Next, the NDT are then conducted on the bridge structures. These include the rebound hammer test, UPV test, and electromagnetic cover meter.

In the evaluation phase, results from the site survey; NDT, visual report, and inventory data are analyzed to evaluate the bridge condition. The overall concrete strength of the bridge structure is assessed and the correlation between NDT results and visual ratings are then determined. Eight reports are prepared for each district.

After all data has been analyzed, programming of ANN is commenced. The ANN system used in this study is self developed and programmed using Borland C++ language. Even though there are existing software that enable user to build neural network model without programming (such as Neuroshell 2), developing own program is more preferable in this study. This is because customized program can be designed based on our requirement and changes in the network's parameters can be made according to our analysis, unlike the existing software where certain parameters are fixed. The development of the ANN model begins with selection of variables, determination of network structure, training process, and finally validation process. This ANN model is used to predict results from NDT and visual ratings using previous data.

Finally, the results and findings from this study will be concluded. The overall results for bridge inspection using NDT method and their correlation with visual ratings are discussed to determine the rationale of applying NDT as a supporting tool in the annual bridge inspection. The accuracy of results predicted by ANN is discussed to evaluate their performance and recommend any improvement that can be conducted in the future to enhance this study.

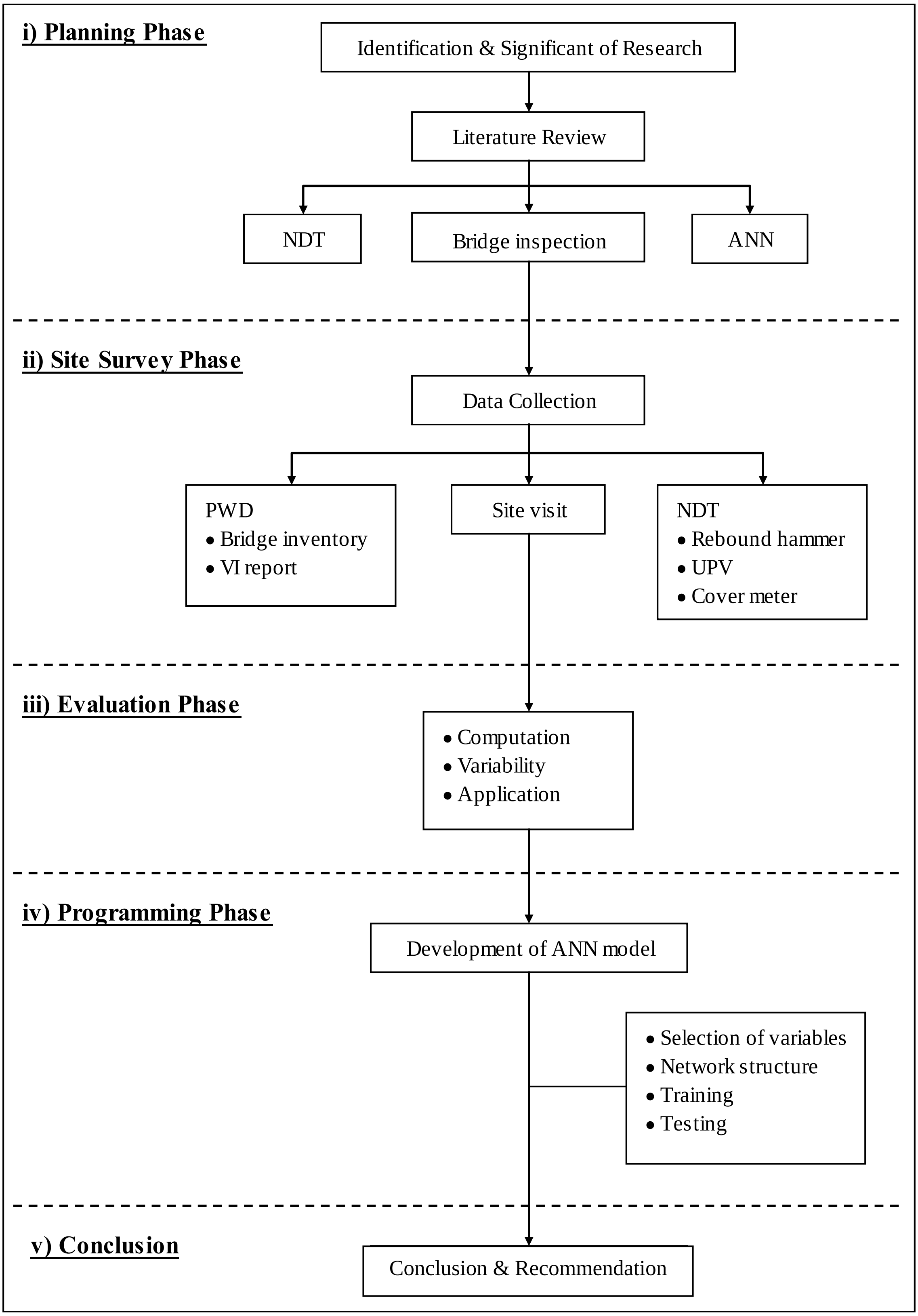

Figure 1.1: Research methodology

1.6 Thesis Flow

This thesis is organized into seven chapters as listed below:

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Theoretical Background
- Chapter 4: Methodology of Research
- Chapter 5: Inspection Results and Discussions
- Chapter 6: The Application of Artificial Neural Network in Rating Prediction
- Chapter 7: Conclusions

Chapter 2 will cover the literature review of each topic in this study. Existing practice in bridge inspection for Malaysia and other countries will be reviewed. The procedures involved and problems occurred will be discussed in brief. The advantages of NDT will be discussed and some applications of NDT in bridge area will be reviewed. This will lead to the discussion of integrating NDT with Bridge Management System. Next, brief background of ANN and its capabilities are outlined. Some examples of their applications in civil works and bridge engineering will be discussed.

Chapter 3 will discuss more on the theoretical background. This chapter will be divided into two main parts; theoretical background of NDT and ANN. Three types of NDT will be covered; rebound hammer, UPV, and electromagnetic cover meter. In the second part, every component in the neural network structure is discussed and the procedure involved in developing and operating a neural network will be reviewed. A complete procedure of backpropagation network is given in this chapter.

In Chapter 4, the methodology applied in this research will be discussed in detail. As in Chapter 3, this chapter will be divided into two main parts; nondestructive testing and methodology of ANN. The method of inspection is discussed thoroughly. This will cover the step-by-step procedures, site testing, pictures, and method in analyzing data. As for the ANN, the discussion will be focused on every stage of the ANN development. It starts from data analysis, followed by the development of ANN structure, and the process involved which include training process, testing, and finally validation phase. The ANN system developed in this study is reviewed at the end of this chapter.

Chapter 5 will concentrate on the findings, analysis, and results from NDT. Statistical analysis on bridge samples will be discussed prior to the test results. Next, Rebound hammer and UPV test results will be discussed. The discussion will be focused on concrete uniformity and correlation of the test results with concrete strength. These results will be used in developing the ANN together with the visual inspection and inventory data from the PWD.

Chapter 6 will focus on the findings, analysis, and results from the application of ANN in bridge inspection. First, results from data analysis are reviewed. These include the characteristic of data used, classification of data used in the testing and validation process, and data normalization. Next, the output from variables and hidden neurons selection are discussed which will lead to the determination of neural network structure applied in this study. Finally, results from the training, testing, and validation phase are outlined. Comparison between the actual rating and the predicted value given from the ANN are made to evaluate the neural network's performance.

Finally Chapter 7 will conclude all the discussion and findings in this thesis. All findings should be concluded and answer each of the objectives as been outlined in section 1.3. These include the condition of the selected bridges based on nondestructive evaluation, correlation between the NDT results and visual inspection conducted by the PWD inspectors, the most suitable parameters needed in developing the ANN for bridge inspection, and finally the evaluation on the performance of the neural network to be used as a supporting tool in bridge inspection process. Recommendations for future development will also be reviewed in this chapter.