INTEGRATED BRIDGE HEALTH MONITORING, EVALUATION AND ALERT SYSTEM USING NEURO-GENETIC HYBRIDS

RENI SURYANITA

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Universiti Teknologi Malaysia

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This thesis is dedicated to my husband, Harnedi Maizir, and my children; Raihan, Hirzy, and Rania and also to my lovely parents, Syahmunir Syam and Syamsiar. Their patience, support and encouragement made my PhD completed.

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ABSTRACT

The bridge monitoring system which can analyze and predicts damage level of bridges due to earthquake loads is not yet available in Malaysia. Even though Malaysia is not an earthquake-prone country, earthquake from neighboring countries could affect the stability of the existing bridges in Malaysia. This study aims to analyze the performance of the bridge subject to earthquake loads and develop the intelligent monitoring system to predict the bridge health condition. The case study is the Second Penang Bridge Package-3B. The Intelligent System consists of the Artificial Neural Networks (ANN) and Genetic Algorithm (GA) hybrid model to obtain the optimum weight in the prediction system. The ANN inputs are 4633 data of the bridge response accelerations and displacements while the outputs are the bridge damage levels. Damage levels are obtained through nonlinear time history analyses using SAP2000. The damage level criterion is based on FEMA 356 focusing on Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) level. This intelligent monitoring system will display the alert warning system based on the prediction results with green for IO, yellow for LS and Red color for CP level. According to the results, the best performance of the displacement as data input in the prediction system is 2.2% higher than the acceleration data. This study is verified with pushover-static test to the mini-scale piers model in ratio 1:34. The first crack occurred on the base of Pier 1 when the lateral load is 9 kN, 12 kN for Pier 2 and 8 kN for Pier 4. Maximum displacement at Pier 1 is 10 mm while at Pier 2 and Pier 4 is 6 mm individually. The intelligent monitoring system can greatly assist the bridge authorities to identify the bridge health condition rapidly and plan the bridge maintenance routinely.

ABSTRAK

Sistem pemantauan jambatan yang boleh menganalisis dan meramalkan tahap kerosakan jambatan akibat beban gempa bumi masih belum didapati di Malaysia. Walaupun Malaysia bukan negara yang terdedah secara langsung kepada gempa bumi, dikhuatiri ancaman gempa bumi dari negara-negara jiran boleh menjejaskan kestabilan jambatan yang sedia ada di Malaysia. Kajian ini bertujuan untuk menganalisis keupayaan jambatan akibat beban gempa bumi dan membangunkan sistem pemantauan pintar yang boleh meramalkan keadaan kesihatan jambatan. Kes kajian ialah Jambatan Kedua Pulau Pinang-Pakej 3B. Sistem pintar terdiri daripada campuran algoritma genetik (GA) dan jaringan neural tiruan (ANN) untuk mendapatkan pemberat optimum di dalam sistem ramalan. Data masukan ANN ialah sejumlah 4633 data pecutan dan anjakan dari tindakbalas struktur jambatan manakala data hasil ialah tahap kerosakan jambatan. Tahap kerosakan diperolehi melalui analisis riwayat masa tidak linear menggunakan perisian SAP2000. Kriteria tahap kerosakan berdasarkan FEMA 356 memberi tumpuan kepada kerosakan ringan (IO), kerosakan sedang (LS) dan kerosakan teruk (CP). Sistem pintar ini memaparkan sistem amaran jambatan berdasarkan ramalan hasil kajian mengikuti kaedah warna hijau untuk tingkatan IO, kuning untuk tingkatan LS dan merah untuk tingkatan CP. Berdasarkan hasil kajian, data anjakan memberikan pencapaian terbaik sebesar 2.2 % lebih tinggi daripada data pecutan. Kajian ini disahkan dengan menggunakan pengujian tolak-tarik statik untuk model jambatan skala mini dengan nisbah 1:34. Keretakan pertama terjadi pada dasar model tiang 1 pada masa pembebanan sisi 9 kN, manakala model tiang ke 2 dan ke 4 terjadi pada masa pembebanan sisi 12 kN dan 8 kN. Anjakan maksimum pada tiang 1, tiang 2, dan tiang ke 3 masing-masingnya ialah 13 mm, 7 mm dan 6 mm. Sistem pemantauan pintar boleh membantu pihak berkuasa jambatan untuk mengetahui keadaan kesihatan jambatan dengan pesat dan penyelenggaraan jambatan dapat dilakukan secara rutin.

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LIST OF SYMBOLS/TERMINOLOGIES

Activation - Mathematical function that determines the output signal level of a processing element (neuron) from the input signal levels.

Bias - An offset to the activation function.

c - Damping coefficient

Crossover - Recombination operator to select at random a pair of two individual strings for mating.

E - Root-mean square

Epoch - A complete pass during which all the training data are presented in the learning algorithm.

f - Natural frequency

Hidden layer - The grouping of the processing elements (neurons) that is hidden from direct connection to points outside of the Artificial Neural Network.

Input layer - The grouping of the neurons that feed data into the Artificial Neural Networks

J - Set of training examples

k - Stiffness

[K] - Stiffness matrix

Learning rate - A factor used to scale the rate at which the weights in the Artificial Neural Network is adjusted during training.

m - Mass

Mutation - A process after cross over for changing the string from 0 to 1 and vice versa.

N - Number of errors

Neuron - Processing element, node, and unit.

Output layer - The grouping of the neurons that feed data out of an Artificial Neural Network.

r - The capacity/demand ratio

T - Periode

Training - A set of inputs used to train the Artificial Neural Network.

$\{U\}$ - The global unbalanced joint force vector

Validation - A data set used to tune or adjust the parameters of Artificial Neural Networks during training.

Weight - The strength of a connection between two processing elements

x - Displacement

(γ) - Function

Δ_c - Displacement capacity of the bent from pushover analysis

Δ_{NS} - Sum of any non-seismic displacement demand

Δ_{EQ} - Seismic displacement demand from response spectrum analysis.

$\{\Delta\delta\}$ - Displacement

$\{\Delta F\}$ - Load

$\{\Delta\delta_r\}$ - Imposed displacement vector

$\{\Delta R\}$ - Reaction vector

$\{\Delta F_f\}$ - Incremental joint load vector

$\{\Delta\delta^t\}$ - Total global displacement increment vector

$\{\Delta\delta_e^t\}$ - Individual member deformation increment vector

$\{\Delta F_e^t\}$ - Element force increment vector

η - Learning rate

ξ_n - Damping ratio

ϕ - Mode shape

ω - Angular frequency

$[A]^T$ - Transformation matrix

$\ddot{x}$ - Acceleration

$\dot{x}$ - Relative velocity

$\ddot{x}_g$ - Acceleration of earthquake

C_n - Generalized damping

c_{cr} - Critical damping

$[k_e]$ - Individual element stiffness matrix.

K_n - Generalized stiffness

M_n - Generalized mass

O_j	-	activation value
P_n (t)	-	Generalized loading
R_d	-	Maximum relative displacement of SDOF
T_j	-	Target output
(u_i)	-	Inputs
(w_i)	-	Sums the products of the weights
(w_0)	-	Bias
$U_i^{'}$	-	Normalized input value
F_i	-	The fitness value
U_i	-	Original data
U_{max}	-	Maximum values
U_{min}	-	Minimum values

CHAPTER 1

INTRODUCTION

1.1 General

Bridges are indispensable structures to connect two places throughout the transportation system. The bridge should have an enough strength capacity to withstand the self-weight and moving loads on the deck. Construction of the bridge shall be supervised by the bridge authorities in order to obtain long service life, ensure public safety, and reduce maintenance costs. Operation and maintenance of bridges become more complex with the increased age of the bridges. One of the essential efforts to know the life cycle performances and management procedures of bridges is through Structural Health Monitoring (SHM). According to Wenzel (2009), SHM refers to the implementation of a damage identification strategy for Civil Engineering infrastructures. Application of SHM in Bridge Engineering aims to ensure long service life and improve the high level service to the highway users. Moreover, the objectives of bridge monitoring are to ensure bridge safety; to provide a better maintenance planning; to extend the life of deficient bridges; and to improve the knowledge of structure. Bridge monitoring is also used to track any aspect of performance or condition of a bridge in a proactive manner, using measured data and analytical simulation (Pearson-Kirk, 2008).

The concept of health monitoring can be explained in terms of the goals of preventive health management in medical sciences. The diagnosis and precaution due to common ailments at a sufficiently early stage are the best option as the chances of curability are significantly higher. The potential in applying this concept in many

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CHAPTER 1

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1.1 General

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The concept of health monitoring can be explained in terms of the goals of preventive health management in medical sciences. The diagnosis and precaution due to common ailments at a sufficiently early stage are the best option as the chances of curability are significantly higher. The potential in applying this concept in many aspects such as in Bridge Engineering in order to replace time-based maintenance with a symptom or health-based maintenance are well established (Chang, 2001).

SHM can also help the owners, builders and designers of structures in rational decision making (Huston, 2011). In developing countries, bridge evaluation and maintenance still uses the conventional method such as Non Destructive Test (NDT) and Visual Inspection (VI). This conventional approach should be developed if the bridge authorities want to implement the systems and existing technologies similar to the bridges structural health monitoring system as adopted by the modern countries before. The variation of bridge data and information in bridge SHM should be recorded in real time so that the bridge structure can be observed in the monitoring room or remote area using internet connection. Therefore, the experts rationally should make the right decisions based on the bridge SHM results.

1.2. Problem Background

In the past decade, traditional SHM combines visual observations and heuristic assumption with mathematical models of predicted behaviour. Currently, the modern SHM system which includes the sensors, and automated reasoning techniques have been applied in bridge monitoring. There are many uncertainties or factors in the bridge projects have the high impact for the stability of bridge structures. Among the factors are human errors that caused by the low level of engineers' knowledge and experience on construction and method of implementation. The failure in the bridge construction can cause catastrophic damages in element of a bridge and might even lead to the collapse of bridge structures. One example is the I-35W Bridge in Minneapolis, Minnesota designed in 1964 and opened to traffic in 1967, which collapsed suddenly on August 1, 2007 as shown in Figure 1.1. The investigation reveals the I-35W Bridge collapse is caused by human errors that using undersized gusset plate in bridge construction (Hao, 2010). Another example is the collapse of the Kutai Kartanegara Bridge in East Kalimantan Indonesia on 26 November 2011, approximately 10 years after construction completed, as shown in Figure 1.2. Touted as Golden Gate Bridge of

Indonesia, the longest suspension bridge in the country at 710 m length, collapsed in less than 20 seconds. The evaluation and investigation team which is appointed by Indonesia's Ministry of Public Works announced that the cause was an accumulation of problems that included brittle bolts, lack of standards, fatigued materials, and improperly performed maintenance. These problems led to fatal stress to the bridge. The failure occurred when engineers were jacking underneath one side of the bridge deck at mid span. The structural stress caused by previously undetected problems was exacerbated by maintenance that was not managed correctly (JPCL, 2012). Both the examples indicate that the human errors such as poor supervision and unethical builders ware compounded by flawed specifications and lack of standards have been identified as the cause to the larger problem in many aspects such as human safety, damages of public facilities and economics.

Figure 1.1 One section of the I-35W Bridge collapse (Stambaugh and Cohen, 2007)

Figure 1.2 Kutai Kartanegara Bridge before and after collapse (JPCL, 2012)

Natural disaster such as an earthquake can affect the stability of bridge structures. The proximity of the bridge to the fault and site conditions influences the intensity of ground shaking and ground deformations, as well as the variability of those effects along the length of the bridge. The likelihood of damage increases if the ground motion is particularly intense, the soils are soft; the bridge was constructed before modern codes were implemented, or the bridge configuration is irregular. Even a well-designed bridge may face damage as a result of increased vulnerability of the bridge to non-structural modifications as well as structural deterioration due to earthquake loads. Despite these uncertainties and variations, a lot can be learnt from past earthquake damage, because the type of damage occurs repetitively. Unfortunately, there is a little monitoring system currently available which can evaluate and analyze the bridges due to earthquake.

In Malaysia, bridge monitoring system is not focussed for seismic monitoring, however the monitoring system which done by Public Work Department (Jabatan Kerja Raya) was addressed for routine maintenance due to vehicle loads. Therefore in this study, the monitoring system is focussed for evaluation and prediction the damage level of bridges due to earthquake loads which can be accessed for public. Even though Malaysia is not an earthquake-prone country, it is feared that the threat of an earthquake from neighbouring countries could affect the stability of the existing important structures in Malaysia as shown in Figure 1.3. The nearest threat is from North Sumatera earthquakes, which is about 275 km from the Penang Island-Malaysia. Therefore, the seismic hazard from the neighbouring countries should be aware by Malaysia Government, especially for high-risk structures such as the long span bridges and high stories' buildings.

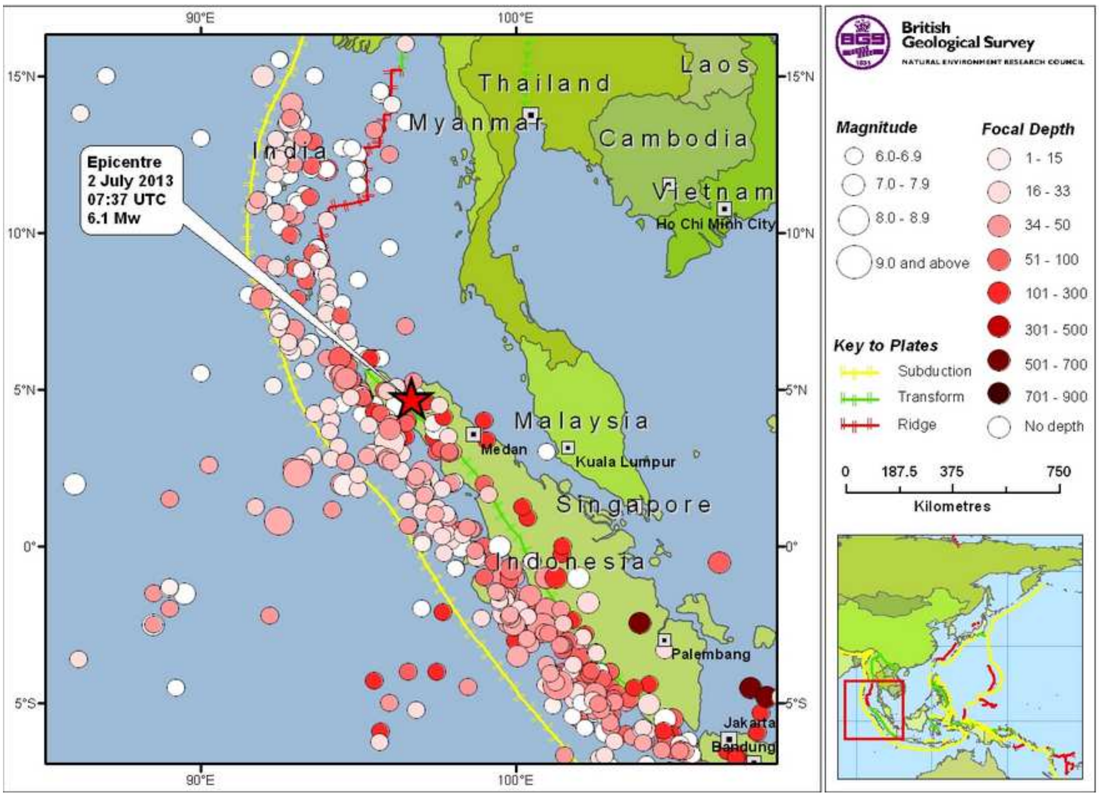

Figure 1.3 The threat of the Sumatera earthquakes to Malaysia region (www.bgs.ac.uk).

There are little studies for short-term and long term bridge monitoring in Malaysia. A few researchers have conducted the study about bridge assessment and visual inspection in Malaysia such as Adnan et al (2006) for 75 concrete bridges on federal highway in Johor state and Khaw et al. (2010) for Sungai Pinang Bridge in Pinang Island. Other researchers, Brownjohn and Moyo (2001) have conducted a study about monitoring of the prestressed box girder Singapore-Malaysia Second Link (Tuas Link) during construction. The bridge is 1.9 km long, and consist of 27 spans, which was completed in mid 1997 and opened to traffic in the same year (Figure 1.4). The monitoring of Tuas Link Bridge aims to observe the bridge's response due to heavy vehicles and ground motions and provide critical information for the design and construction of similar bridges.

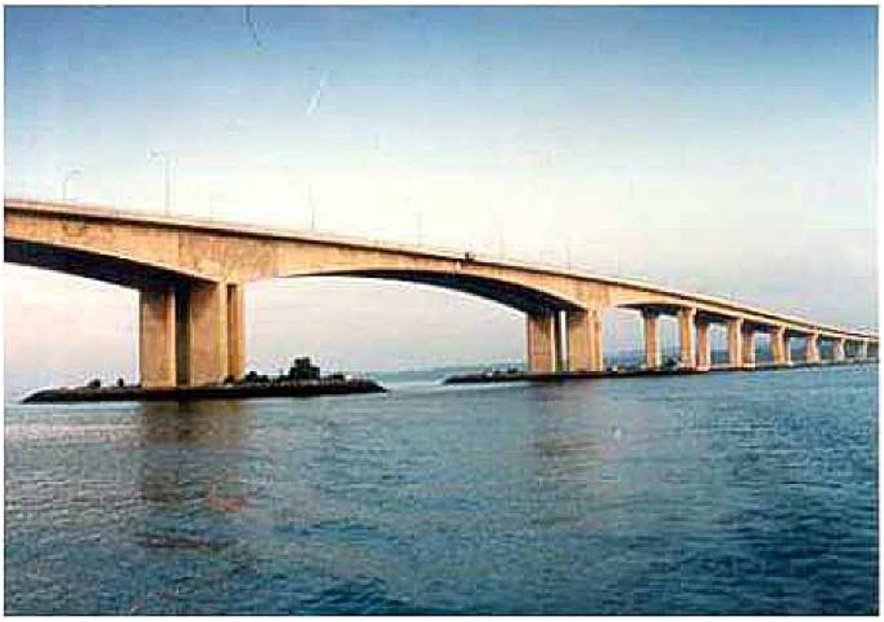

Figure 1.4 Singapore Malaysia Second Link (Omenzetter and Brownjohn, 2006)

Other than human error and earthquake threats, the construction age also contributes to the problems faced by the bridge authorities. Several examples in the literatures demonstrate that the construction age of a bridge is a good indicator of likely performance, with higher damage levels expected in older construction than in newer construction. The older construction was based on significantly lower design forces and less stringent detailing requirements compared with current requirements (Chen and Duan, 2003). The older bridge was confined to older structures built more than 30 years ago and before the introduction of modern seismic codes (Buckle, 1995). One of the examples is the effect of construction era on Routes 3 and 5 of the Hanshin Expressway in Kobe while the Kobe earthquake occurred Route 3 was constructed from 1965 through 1970, while Route 5 was completed in the early to mid-1990s. The two routes are parallel to each other, with Route 3 being farther inland and Route 5 being built largely on reclaimed land. Despite the potentially worse soil conditions for Route 5, it performed far better than Route 3. Route 3 has been estimated to have sustained moderate to large-scale damage in 637 piers, with damage in over 1300 spans and approximately 50 spans need replacement as shown in Figure 1.5.

Figure 1.5 Higashi-Nada Viaduct collapse in the 1995 due to Kobe earthquake (Chen and Duan, 2003)

At the same time, the Route 5 has only been lost a single span owing apparently to permanent ground deformation and span unseating as shown in Figure 1.6.

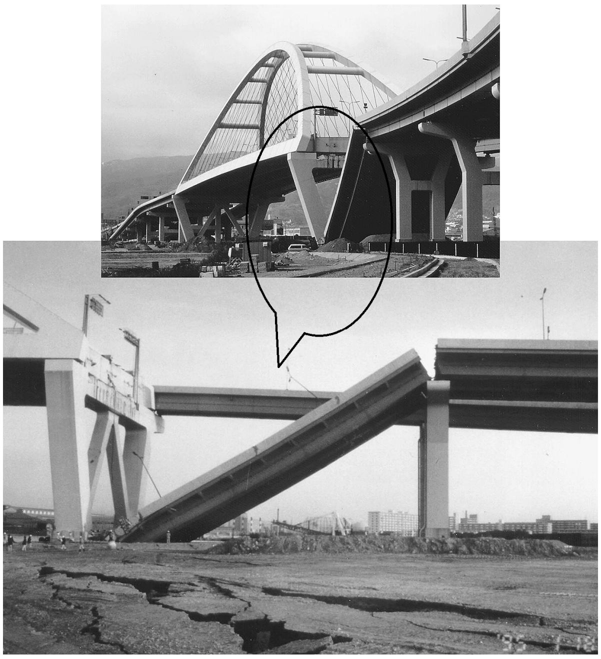

Figure 1.6 Nishinomiya-ko Bridge approach span collapse in the 1995 due to Kobe earthquake (Chen and Duan, 2003)

In order to mitigate major problems, it is very important to monitor the condition of the bridges before the onset of problems. Bridge authorities should understand that to obtain long service lives and to reduce maintenance costs, correct actions must be implemented right from the design and construction phases. The actions must also be implemented with bridge management systems for service stage. This management system will assist in maintenance decision making by considering both structural safety and economy. The monitoring of bridges is also designed to extend the lifetime of deficient bridges and to improve the knowledge of the structure. The complexity and problem size in seismic monitoring and analysis of bridges disallow the use of conventional method for problem solving.

Currently, problems faced in a conventional bridge monitoring system are divided into system and human problems. The system problems include the errors to interpret monitoring data and slower report generation and submission to database system (server). Furthermore, there is no existing system that is able to unite bridge monitoring and analysis in a combined Artificial Intelligent (AI) system to interpret and predict the damage level of bridge structure due to earthquake load. Many AI systems have successful to solve the Civil Engineering problems such as Neural Networks, Fuzzy Logic and Genetic Algorithms. The Neural Networks have the ability to model the non-linear relationship between a set of input variable and the corresponding outputs without the need for predefined mathematical equations. In addition to that, Neural Networks do not need prior knowledge of the nature to the relationship between the model inputs and corresponding outputs. Comparison to traditional methods, Neural Networks tolerate relatively imprecise, noisy or incomplete data. Approximate results are less vulnerable to outliers, have better been filtering capacity and more adaptive. This enables Neural Networks to overcome the limitations of the existing methods and successful in be applied on many problems within the field of Civil Engineering. Several researchers have done the study about acceleration and displacement data as the input domain in Neural Networks such as Ok et al. (2012) and Qian and Mita (2008). However their studies are not discussed in detail. Therefore in this study the acceleration and displacement data domain will be combined with time domain of bridge structure response due to earthquake loads in Neuro-Genetic Hybrids and the results are expected more accurate and precise for bridge damage prediction. These results will be compared with acceleration and displacement data without time domain for validation of the input data.

Meanwhile human problems include inconsistence and subjective while reading data, and also insufficient knowledge to analyze lacking of interaction between visible defects and invisible structural degradation. On the other hand, data entry was done manually caused the time consuming. In practice, the monitoring-results are decided according to the level of expertise of engineers. Therefore, the accuracy and reliability of the results are pretty much subjective of the engineer experiences. Thus, the inexperienced engineers require special training before they go into the field. They should understand the fundamental knowledge of bridge engineering not only in theory but also in application to project. Therefore, the errors occurred while performing analysis and interpreting data reading can be solved and minimized uses Artificial Intelligent methods. The Artificial Intelligent method which is applied in this study is Neuro-Genetic hybrids method. The Neuro-Genetic Hybrids method consist of Artificial Neural Networks and Genetic Algorithms as numerical modelling techniques. In the published literature, the Neuro-Genetic Hybrids method which is used in bridge health prediction based on acceleration and displacement time series as input values and damage level (Immediate Occupancy, Life Safety and Collapse Prevention) as output values have not been studied in detail by other researchers. This intelligent method can be applied to the monitoring system for prediction of the bridge performances during and after the earthquake and getting the optimum weight more accurate and rapidly. The term of weight in Artificial Intelligent is the strength of a connection between two processing element which can adjusted to reduce the overall error in the monitoring system.

The intelligent bridge monitoring system in the study is proposed to apply on the Second Penang Bridge. The Second Penang Bridge is a 24 km long and 16.9 km above seawater, connecting Peninsular Malaysia and Penang Island. The bridge which is completed in 2013 becomes the longest bridge in Malaysia and Southeast Asia. Additionally, the Second Penang Bridge has been design for earthquake used the 475-year time period with PGA 0.1773g and the 2500-year time period with PGA

0.3262g. Therefore, the Second Penang Bridge is suitable for a case study in bridge seismic monitoring system.

The pushover test is required to obtain the behavior and possibly the failure mechanisms of the Second Penang Bridge piers. The testing is also to validate the finite-element analysis which has been done. The pier model is mini scale which aims to reduce the cost and make simple the model fabrication. In general, numerical models are typically suitable for predicting the elastic response however they are often not very accurate in predicting the inelastic response such as force and displacement capacity. Therefore, pushover test is required to understand the behavior of pier structure when subjected to seismic loading because during design earthquake, structures are expected to respond in the inelastic range.

In general, seismic monitoring is separate with seismic analysis system. Sometimes the analysis is performed after the monitoring results obtained. Additionally, the analysis is based on the expertise of engineers in the process of monitoring results. In this study, analysis system is integrated with intelligent system, therefore it can be used to predict damage level of bridges in seismic zone include the high and low earthquake region.

1.3 Problem Statements

According to problem background, the problem statements can be summarized as follows,

(i) The responses of bridge structure that include acceleration and displacement time histories due to earthquake loads are required to be input values in intelligent monitoring software.

(ii) Intelligent Monitoring Software needs optimum weight through Neuro-Genetic Hybrid for prediction of damage level rapidly.

(iii) The numerical model are not very accurate in predicting the inelastic response, therefore pushover test is required to understand the behavior of pier structure model.

(iv) There is no existing bridge monitoring system that is able to unite bridge monitoring and analysis using a Neuro-Genetic Hybrid system to interpret and predict the bridge condition and damage level of bridge due to earthquake loads.

1.4 Objectives

The objectives of the research can be stated as;

(i) To study the performance of the acceleration and displacement time histories of bridge structure response due to earthquake loads as input domain in training and testing process of Artificial Neural Networks using one and two hidden layers.

(ii) To obtain the optimum weight for prediction of damage level rapidly through Neuro-Genetic Hybrids.

(iii) To determine failure mechanisms of the mini-scale of pier models using pushover test and predict damage level using Neuro-Genetic Hybrids.

(iv) To conduct the intelligent seismic monitoring system by integrating the analysis, damage level prediction and seismic early-warning system for a bridge structure.

1.5 Scope and Limitations

The results of the study can be affected by several variables and factors involved. Therefore, the scopes and limitation should be defined clearly in order to conduct the good results as mentioned in the objectives of study. The scope and limitation in this study are:

(i) The case study is Second Penang Bridge package 3B from CH 16913 m until CH 17015 m. The bridge is a prestressed concrete with 3 spans. The total of the bridge is 102 m length.

(ii) Analysis uses the dynamic non-linear method on SAP2000 ver.14.2. The bridge is analyzed based on 12 earthquakes from Pacific Earthquake Engineering Research database and two earthquakes from Malaysian Meteorological Department (MMD).

(iii) Damage level occurred based on Federal Emergency Management Agency (FEMA) 356. The damage levels are Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) using Non linear Time History Analysis.

(iv) Development of damage level prediction on bridge structure uses Neuro-Genetic Hybrid, which includes Neural Networks and Genetic Algorithms. Input data for training in Neural Networks are accelerations, displacements and time series from the finite-element modelling results. Total of data is 4633. Data is used for training is 70% of total data, while data is used for testing and validation, 15% of whole data respectively. Neuro-Genetic hybrid is trained and optimized used MATLAB Programming 2010 version under UTM license.

(v) Laboratory test for bridge model is done at the Laboratory of Structure and Material Universiti Teknologi Malaysia, Skudai Johor Bahru. Bridge model has been produced through equation derivation of similitude laws. Bridge design used AASHTO and Eurocode 8 part-2. The scaled down of a model has been constructed at laboratory and tested using several sensors.

(vi) Development of an intelligent system for bridge monitoring due to earthquake loads. The intelligent monitoring system is conducted through Visual basic programming.

1.6 Organization of Theses

The study is divided into eight chapters. The content of each chapter is summarized as follows,

Chapter 1 Introduction, this chapter describes the study background and the objectives to be achieved. Furthermore, the scope and limitations of study, the organization of theses and the outcome of research to be conducted are explained at the end of this chapter.

Chapter 2 Literature Review, this chapter discusses about several bridges seismic analyses from other researchers, intelligent monitoring system and application hybrids of Neural Networks and Genetic Algorithms to find the better prediction the damage level under earthquake loads. The end of this chapter is a summary of the literatures that has been reviewed within this chapter.

Chapter 3 Theoretical Background, this chapter shows the fundamental knowledge of a bridge seismic performance-based design and seismic response analysis for the linear and non linear response. This chapter also explains the theory of Neural Networks and Genetic Algorithms, and combination of the both in Neuro-Genetic hybrids.

Chapter 4 Research Methodology, this chapter explains the step by step to solve the problem and achieve the results of study. The step starts in a preparation model for simulation and experimental until the installation of sensor in a bridge model. The methodology includes the flowchart and algorithms of Neural Networks

(NN) and Genetic Algorithms (GA) process. The end of this chapter, the procedures of intelligent monitoring systems are also included.

Chapter 5 Concrete Bridge Behaviours under Earthquake Load, this chapter describes the material properties of bridge model and earthquakes' excitation data from Pacific Earthquake Engineering Research Centre (PEER) and Malaysian Meteorology Department (MMD). This chapter also includes the behaviour of the bridge model that has been analyzed based on non linear time history analysis to find the bridge acceleration and displacement response.

Chapter 6 Application Neuro-Genetic Hybrids in Bridges Seismic Monitoring System, this chapter explains about the term of Artificial Intelligence includes Neural Networks, Back-propagation, Genetic Algorithms and hybrid of the Neural Networks and Genetic Algorithms. The last of this chapter shows the comparison of the acceleration, displacement and time data as an input domain in Neuro-Genetic hybrids in one and two hidden layers.

Chapter 7 Implementation of Intelligent Seismic Bridge Monitoring System using Experimental Test, this chapter explains the preparation and calibration of a bridge model using pushover frame at Structure and Material Laboratory-UTM and how the sensor and data acquisition are installed in the networking and communication system. The chapter also analyzes the result of laboratory test to know the behaviour of piers' models.

Chapter 8 Conclusions and Recommendations, this chapter concludes and summaries the results on the previous chapters and explains the advantages of using Neuro-Genetic Hybrids in bridge monitoring software. The final of the chapter consists of the recommendation for the further study.

1.7 Research Finding

Given the innovative and ambitious objectives and the scope expected from the health monitoring paradigm, it is important to produce a digital form of the intelligent seismic system for bridges. The monitoring and analysis tools can be operated in computer unit or mobile devices. The major novelties adopted the hybrid of Artificial Neural Network (ANN) and Genetic Algorithm (GA) as known as Neuro-Genetic Hybrids, which act as the intelligent components that facilitated the systems for forecasting of seismic performance and damage level.

In current practice, the monitoring and data analysis were not integrated in a single system. Hence, the Neuro-Genetic Hybrids in this system will use the finite-element results to generate the bridges seismic performance and damage levels. Besides serving as a handy, the convenience monitoring tools, the major key feature of this system is the capability to continuously ‘train and learn’ by itself through the increasing input obtained from the numeric simulation and field data. Therefore, this system will benefit broad user groups ranging from the site inspectors to structural engineers. This is because the system is not just a monitoring tool with the alert system for public, but at the same time the system is capable of control construction procedures and phases while analyzing and forecasting future behaviour of bridges at any given time duration.

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