CHAPTER I

INTRODUCTION

1.1 Background and Research Motivation

The information of axle loads of vehicles in normal traffic condition has been a subject of interest of engineers for many years, since they are the important parameters for the design of new bridges and pavements, the assessment of existing pavements and bridges, the traffic studies, the design code calibration, live load model development, and the pavement and bridge maintenance planning among other things. The road and bridges design live loads are mainly dominated by heavy vehicles such as trucks and trailers since their passages produce large impact loading which cause the pavement and structural damages. Although the vehicle axle weights are specified by the weight limit regulation, the overloading is still a biggest problem that has not as yet been satisfactorily addressed. To enforce the weight limit requirements in the transportation network, weigh stations have been traditionally used to weigh vehicles and impose fines and/or penalties for exceeding weight limits. The weighing requires vehicle stopping which takes a long time to process for each vehicle. The queuing also induces traffic congestion which causes the observation by weighing at the station not able to be done thoroughly. When queue lengths extended from the ramps into the mainline lanes on the highway, trucks would be turned away from weigh stations merely because there was not enough capacity. When trucks are turned away, enforcement levels are reduced and overweight vehicles would be able to continue traveling on the highway. Therefore, to obtain this vehicle axle loads information without disturbing the traffic, the Weigh-In-Motion (WIM) system was adopted and developed to indirectly measure the vehicle axle weights.

In the past twenty years, many countries have utilized the WIM technology to reduce delay and increase enforcement of overweight vehicles. WIM was defined by the American Society for Testing and Materials (ASTM) as the process of estimating a moving vehicle's gross weight and the portion of that weight carried by each wheel, axle, or axle group, or combination thereof, by measurement and analysis of dynamic vehicle tire forces. Through the WIM technology, the vehicles can be weighed dynamically without disturbing their traveling speeds.

Although WIM has improved weighing station operations, there are various types of WIM scales with various levels of accuracy. As weighing accuracy decreases, the number of vehicles that must proceed to the static scale increases in order to ensure that all potential overweight vehicles are weighed on the static scale. Additionally, if WIM underestimates a vehicle's weight, violating trucks could then potentially go through the system without being stopped.

The existing technologies used in WIM scales are bending plates, piezoelectric sensors, and load cells. Although, these systems do not disturbed the traffic flow, the installation systems based on weighing detectors are embedded into the pavement and disturb the traffic during their installation and maintenance. Moreover, the system installation and maintenance costs are also expensive. The new alternative system called Bridge Weigh-In-Motion (B-WIM) was then developed. The B-WIM system deals with the existing instrumented bridge or culvert from the road network. The advantages of this system are that it can be installed and maintained without disturbing the traffic flow and the drivers passing through the bridge cannot notice that the vehicle loads are being detected. Additionally, the costs of installation and maintenance of the B-WIM system are lower than the existing WIM. Hence, the identification of dynamic axle loads from the bridge responses has become more attractive since it is much cheaper and easier to install and maintain. However, the accuracy in axle loads identification of B-WIM systems depends on the efficiency of hardware and software.

Based on previous researches, many techniques have been proposed for B-WIM to estimate the weight of vehicles. Among them the two different assumptions of vehicle loads on the bridge, which is either a constant or a time-varying moving load, are often employed. Many theoretical and experimental studies have been proposed to identify and estimate the moving loads. Although the previous studies have found that the identification methods are reliable, most of them rely on the numerical simulation and the experimental investigation. While a broad spectrum of the vehicle parameters and bridge properties can be extensively investigated, it is known that real vehicle-bridge interaction behaviors are complex and might significantly differ from those mathematical models used in numerical simulation or small-scale models used in the experiment. Therefore, the full-scale investigation of moving vehicles on an actual bridge has become a primary interest of this study. In the past, there was a full-scale study on the actual bridge, however, only a limit number of test conditions were considered.

In this dissertation, both small-scale and full-scale tests of moving vehicles on the bridge are performed besides the numerical study on computer simulation. The effectiveness of two identification methods is intensively evaluated under various passing conditions of vehicles. Moreover, the application of the B-WIM to monitor the actual truck weights in the road network is conducted. The information of many trucks in the normal traffic condition, i.e., truck axle weights, gross weight, axle spacing and truck speed are obtained. Bridge live load models from design code such as HS20-44 and Thai truck are compared with this measured truck database from B-WIM. This is a first study in the country which the existing bridge design live load is evaluated and discussed based on actual acquired truck load data using statistical and probabilistic approach.

1.2 Objectives

- To study and improve the accuracy of two identification methods of moving load from bridge bending moments which are (a) Constant magnitude of moving axle loads assumption and (b) Time-varying magnitude of moving axle loads assumption.
- To study the influences of various parameters on the identification methods such as sampling frequency, structural discretization, vehicle configurations, moving formation of vehicles, bridge surface roughness, number and position of response measurements, error of measurement and random vary parameters by computer simulation.
- To evaluate the effectiveness of the identification methods and study the influences of various parameters on their effectiveness such as vehicle speed, vehicle axle weights and travelling paths by small-scale experiment.
- To verify the obtained analytical and experimental results using field test with actual full-scale vehicle-bridge system.
- To actually install the B-WIM system in road network and perform a long-term monitoring of heavy truck information such as truck weights, axle spacing and truck speed in normal traffic condition.

- To evaluate and discuss on the bridge design live load in Thailand by using the collected truck information from installed B-WIM.

1.3 Methodology

The methodology of this research is diagrammatically described as shown in Figure 1.1. The research consists of a numerical study, a small-scale test, a full-scale test and a B-WIM application. The numerical study based on a computer simulation is conducted to investigate the influence of related system parameters of two identification methods of the moving load from bridge bending moments and also as a preliminary study for small-scale and full-scale tests. The small-scale test is carried out in order to verify and evaluate the effectiveness of two identification methods previously investigated in the numerical study. The full-scale test is carried out in order to verify the obtained analytical and laboratory test results and to investigate the feasibility of the method and system toward the real application. The B-WIM system is applied from the full-scale test and is used to collect the information of heavy trucks such as truck weights, axle spacings and truck speeds in an actual normal traffic condition. Employing the statistical and probabilistic approach, the obtained truck databases from B-WIM are used to evaluate the existing bridge design live load such as HS20-44 and Thai truck models.

1.4 Scope of Research

1.4.1 Computer Simulation

- Only one vehicle moving across the bridge with constant speed is considered.
- The vehicle is assumed to have four degrees of freedom.
- The bridge is modeled as one span simply-supported beam.
- The bridge behavior under the moving vehicle is assumed to be linear elastic.
- The Euler-Bernoulli beam model is used excluding shear effect.
- The finite element method is adopted in structural modeling of the vehicle-bridge interaction and the axle loads identification system.
- Vehicles' tires are assumed to be always in contact with the bridge surface throughout the duration of travel.

1.4.2 Small-Scale Investigation

- The small-scaled bridge model is a simply supported bridge made of a steel plate with uniform cross section.
- The bending moment of the bridge is obtained from the strain signal directly measured from the bridge response.

1.4.3 Full-Scale Investigation and B-WIM Application

- The axle loads identification assumed constant speed of trucks.
- The 10-wheel truck is modeled as two concentrated axle loads.
- Only 10-wheel trucks are collected from B-WIM system.

1.5 Dissertation Organization

This dissertation consists of eight chapters. Chapter I presents a general introduction of the research motivation, the research objectives and the arrangement of this research. Chapter II reviews previous research works related to the vehicle-bridge interaction, moving loads identification methods, numerical techniques, the WIM system and bridge live load models adopted in this field. Chapter III describes the theoretical background used in formulation of the vehicle-bridge interaction, the relationship between moving loads and bridge responses and the two moving load identification methods used in this research. Chapter IV presents numerical study in the two moving loads identification methods using a computer simulation with parametric study and effectiveness comparison of both methods. Chapter V represents the experimental investigation of the identification methods by testing with scaled model. Chapter VI verifies the previously obtained numerical and small-scale experimental results by a full-scale investigation. Chapter VII presents the application of B-WIM system to monitor the actual truck data in a normal traffic condition. Then the obtained data is used to evaluate the bridge design live load models such as HS20-44 and Thai truck models. Finally, Chapter VIII summarizes the obtained results, discussion on the effectiveness and limitations of the identification methods, compares the measured truck data obtained in a normal traffic condition with the existing bridge design live load models, and provides recommendations for bridge designers and bridge authorities. In addition, further research study is also addressed.

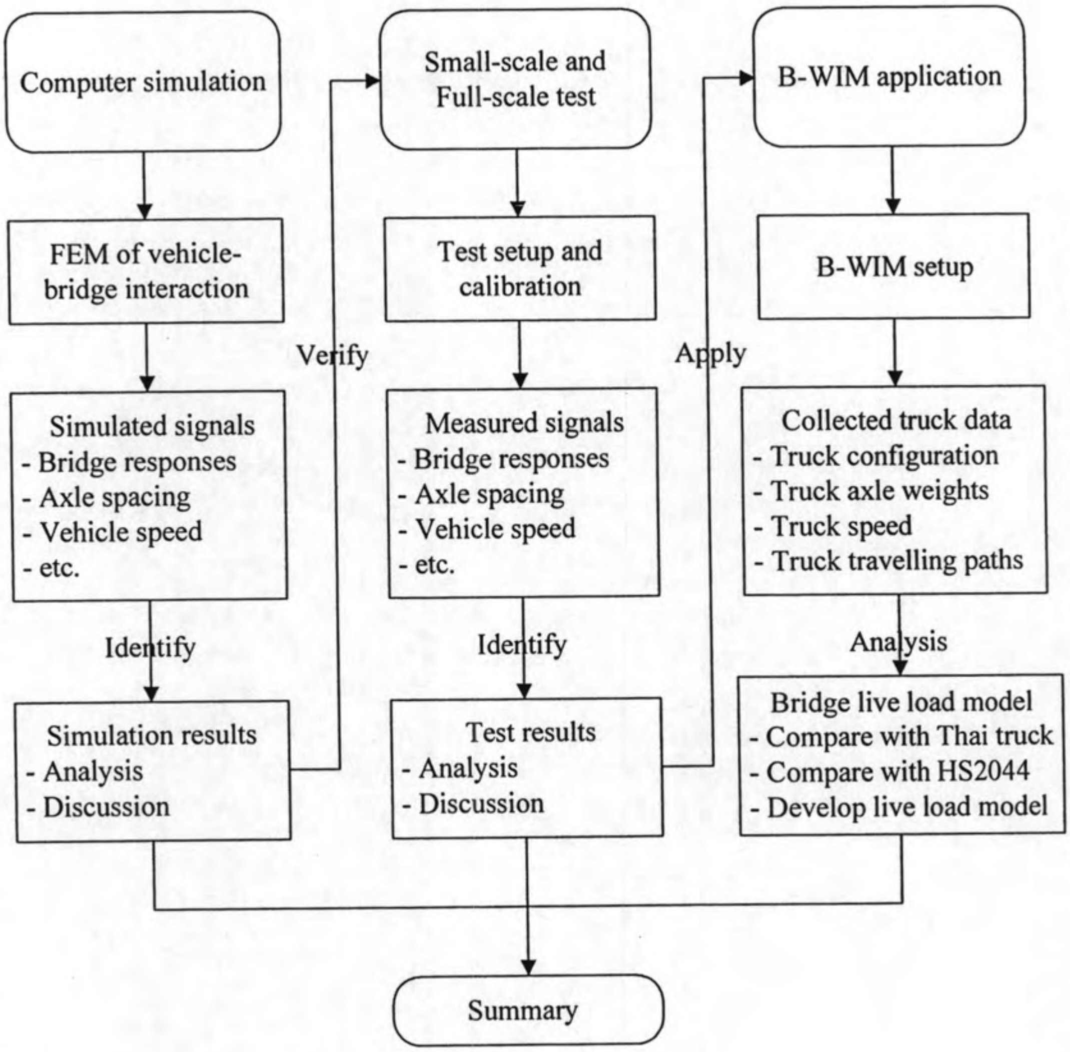

Figure 1.1 Diagram of research methodology