CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Weight estimations of moving vehicle loads from bridge bending moments using Method I (static axle load optimization with influence line) and Method II (regularization with USC technique) are conducted. The comparison of these two methods on their effectiveness and accuracy is carried out. Employing the numerical study, the influences of various parameters are considered. The obtained information is used as the guidance for further experimental and field investigations. The experimental investigation on weight estimation of vehicle crossing the bridge using small-scale tests is carried out in order to verify and evaluate the effectiveness of the identification methods. It has been shown that the identification methods can achieve accuracy level of standard WIM system. However, due to the complexity of real vehicle-bridge interaction characteristic, the field investigation using full-scale tests is carried out in order to verify the obtained numerical and experimental results and to investigate the feasibility and limitations of the identification methods and the system toward the actual B-WIM application. Finally, B-WIM system is installed in a real bridge to collect the information of heavy trucks in a normal traffic condition. The obtained truck records from B-WIM are used to verify and compare with the bridge design live load model such as HS20-44 and the design Thai truck. The detail conclusions for each aspect can be drawn as followings.

8.1.1 Numerical Investigation Using Computer Simulation

The numerical study on weight identification of a vehicle moving on the bridge is conducted in order to investigate efficiency of the identification methods. The influences of various bridge and vehicle parameters are considered. The conclusions for this study are provided as follows:

1. The effective number of finite beam elements employed in structural modeling is 8 elements for a bridge with 10 m span.

2. The sampling frequency rate recommended to be used in data acquisition is at least the five modes fundamental frequency of the bridge.
3. Vehicle having heavier mass and slower speed can be identified with more accuracy than vehicle having lighter mass and faster speed.
4. Vehicle traveling on a smooth bridge surface is more accurately identified than that moving on the rough surface. However, identification for large impact axle load induced by roadway roughness tends to yield large identification error especially for the light weight axle.
5. The three measuring sections seem to be sufficient for the 2-axle vehicle loads identification and the noise is not significantly affected the accuracy of axle weight estimation.
6. The accuracy of axle weight estimation is slightly affected by both axle spacings and axle weight distributions.
7. The error of vehicle position measurement affects the axle weight estimation more than the error of axle spacing measurement.
8. Effect of vehicle transverse positioning can be eliminated by using average sectional bending moments converted from many strain gauges uniformly distributed in each bridge section.
9. Based on the 1,000 cases of random simulation, the three parameters such as axle spacing, the vehicle speed, and the measurement error of axle spacing are strongly influence on the weight estimation errors from the two methods.
10. Based on the 1,000 cases of random simulation, the errors of the gross weight of the vehicle from the two estimation methods are found to be within ±10%.
11. Although Method II exhibits slower speed of computation than Method I. The obtained results indicate that it can provide better weight estimation for almost of the considered cases. Moreover, beside the axle weight estimation, the Method II also provides the identified dynamic axle loads.
12. Compared with the tolerances given by the ASTM standard the results indicate that the system can achieve the accuracy level of type-I for Method I and type-III for Method II, respectively.

8.1.2 Experimental and Field Test Study of Axle Loads Identification

The effectiveness of the vehicle weight estimations is studied through small-scale and full-scale tests. The measured bending moments of a simply-supported bridge at selected sections under a passage of the vehicle are used as the input for the vehicle weight estimations. Their estimation accuracies are evaluated and compared under various parameters of the vehicle-bridge system. The efficiency and robustness as well as limitation of the identification methods are investigated and the obtained results are used for further B-WIM application. The conclusions for this study are provided as follows:

1. From both small-scale and full-scale test results, the vehicle weight and vehicle speed not clearly affect the accuracy of the both estimation methods. Although the numerical simulation results show that the vehicle speed is a strong influence, the small-scale and full-scale test results do not show such characteristic. This is because the speed ranges considered in small-scale and full-scale tests might be not too high.
2. From both small-scale and full-scale tests, the results indicate that the axle weight estimation errors are not strongly affected by vehicle traveling paths. Since, the effect of vehicle transverse positioning on the responses is eliminated by using average sectional bending moments converted from many strain gauges uniformly distributed in each bridge section.
3. From small-scale test results, based on dynamic axle loads identified from Method II, the axle weight identification errors are clearly affected by the vehicle weight and the vehicle moving speed. This is because the bridge responses with smaller dynamic and larger signal to noise ratio usually lead to a more accurate identification than one with larger dynamic and smaller signal to noise ratio. Moreover, it is also observed that the vehicle moving speed has a greater influence on the identification accuracy than the vehicle weight.
4. From both small-scale and full-scale test results, the regularization parameter for Method II is found to be much less sensitive and can be fixed to any number from 0.001 to 10 for small-scale tests and from 1 to 20 for full-scale tests. However, for the appropriate estimation results, the value of 1.0 and 10.0 is simply adopted for both investigations, respectively.

5. Based on these 27 conditions of passing vehicles with 81 runs of small-scale tests, the two methods provide quite accurate weight estimations of the vehicle, i.e. errors < ±6%, in almost of the all cases. Moreover, the obtained results from Method I and Method II can achieve the accuracy level of the WIM system of type-III.
6. Based on these 47 runs of full-scale tests, the two methods provide quite accurate weight estimations of the vehicle, i.e. errors < ±6%, in almost of the all cases. Moreover, the obtained results from both methods can achieve the accuracy level of the WIM system of type-III.
7. Comparing between both identification methods from full-scale test results, it is clearly found that Method I can shorten the processing time almost 6 times over Method II. However, from effectiveness of estimation methods, it is observed that Method II is slightly better than Method I. Moreover, Method II can provide not only the estimated axle weight of the vehicle but also its dynamic axle loads.

8.1.3 Bridge Weigh-In-Motion Application

The Bridge Weigh-In-Motion system is actually applied to acquire the truck data in a normal traffic condition. The obtained 10-wheel truck records are composed of the axle weight, gross truck weight, vehicle configuration (axle spacing), vehicle speed and travelling path of trucks. The records cover approximately 5,049 heavy trucks. The conclusions for this part of study are provided as follows:

1. The records show that the average tandem axle weight and gross weight of measured 10-wheel trucks are 172.31 kN and 217.28 kN, respectively. These results show that the mean truck weight of B-WIM records is not overweight compare with the legal weight limits.
2. There are 901 trucks (17.85%) that exceed legal weight limit for the case of tandem axle weight and 858 trucks (16.99%) that exceed legal weight limit for the case of gross weight. These results show that there are a significant number (more than 16%) of overloaded trucks moving in the transportation network.
3. From bridge live load models study, it is observed that the design Thai truck can be conservatively used to design the bridge with a live load factor

2.17 for 75 years life time, however the HS20-44 might not be conservatively used.

4. By comparing the design Thai truck and HS20-44, it is found that the design Thai truck load seems to be more appropriate than HS20-44. This is because the Thai truck load model is more similar to the 10-wheel trucks which are being used in the present traffic.
5. Based on obtained truck records, the gross weight of the existing design Thai truck may be reduced by 10% with the same configurations providing the live load factor of 2.17.

8.2 Recommendations for Further Study

1. Developments of identification method that can be applied for other type of bridges and can identify a more complicate condition of trucks such as multiple of passing trucks, various configurations of trucks, etc.
2. A Free-Axle-Detector (FAD) technique should be developed and applied to B-WIM system to reduce the difficult of vehicle position measurement.
3. It is interesting to compare the identified dynamic axle loads with the actual loads of the passing trucks
4. For bridge live load model study, more B-WIM records are needed for further accurate evaluation. Therefore, more B-WIM stations should be employed to acquire more truck records and other types of heavy truck in the every main transportation network.
5. Other type of trucks, especially the semi-trailer, should also be acquired for further evaluation of bridge load model.