

Bridge Finite Model Updating Approach By Static Load Input/Deflection Output Measurements: Field Experiment

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ABSTRACT

This paper presents a field experiment validation for a Finite Element model Updating method using moving vehicle load input-deflection output measurements. The proposed approach can update the stiffness matrix by using static input-output measurements and update the mass matrix by using a few natural frequencies obtained from dynamic measurements. Field experiment was carried out to a single span steel plate-girder bridge in Test Road of Korea Highway Corporation. The location of load, deflection and strain were measured during the load test. FE model updating was carried out using measured input-output measurements. The updated result was found to agree with the measured input-output relationship well.

1. INTRODUCTION

Finite Element Model Updating Method can be useful to evaluate structural integrity. Bridges deteriorates after construction due to repeated vehicle loadings and weathering. The deterioration of a bridge can be represented by optimizing structural parameter of a Finite Element model (FEM). Such an updated FE model can be used for evaluating the performance of a bridge. According to the result of evaluation, it is possible to develop a cost-effective maintenance plan. General procedure of FEMU is divided into 2 steps: 1) Modal parameter extracted from field experimental data, 2) Minimizing the difference between the FE model and response of a bridge by optimization algorithm.

This paper proposes a new method for reliable FEMU by combining static Vehicle Input-Deflection Output(VIDO) with ambient vibration measurements of the bridge.

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2. FINITE ELEMENT MODEL UPDATING METHOD

2.1. CONVENTIONAL FINITE ELEMENT MODEL UPDATING METHOD

Conventional FEMU methods were carried out by using modal parameters, i.e., natural frequencies and mode shapes, to tune an initial FE model. Modal parameter based FEMU methods are useful to predict dynamic responses of bridge (Wang, Li, & Li 2010, Macdonald& Friswell 2007, Brownjohn & Xia 2000, Park, Park, & Kim 2014, Bayraktar & Can 2010, Lin, Zhang, Guo, & Zhang 2009, Brownjohn, Moyo, Omenzetter, & Lu 2003). But these methods does not guarantee accurate predictions for static responses of the bridge. To overcome the problem of the modal parameter based FEMU methods, alternatives were used by using static responses(deflections or strains)(Ren, Fang, & Deng 2011), or using both static and dynamic responses (Xiao, Xu, & Zhu 2013, Jung & Kim 2013).

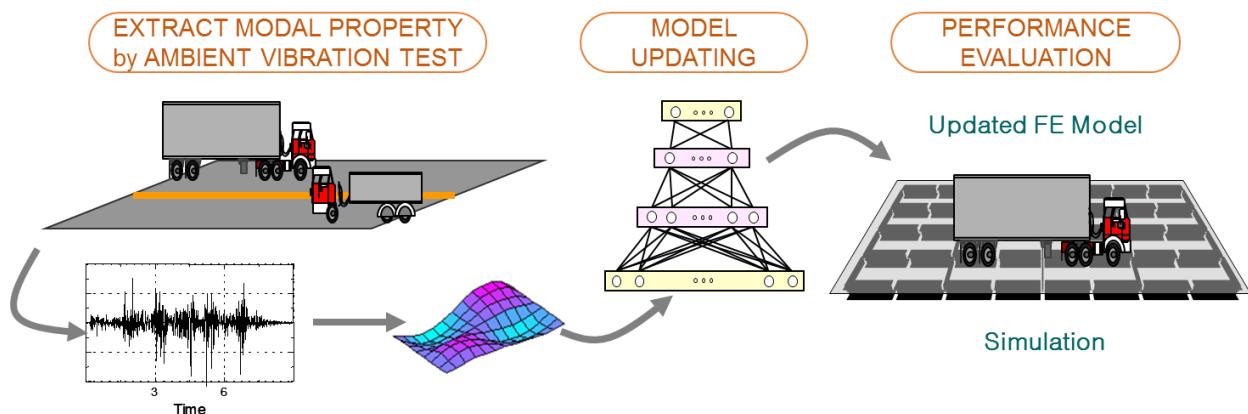


Fig. 1 FEMU method based on ambient vibration

2.2. PROPOSED FINITE ELEMENT MODEL UPDATING METHOD

This paper proposes a new FEMU method which combines static and dynamic measurements. The new method consists of two steps: 1) Optimizing the stiffness matrix of bridge by using vehicle input - deflection output measurement data, and 2) Optimizing the mass matrix of bridge by using dynamic character extracted from the ambient vibration measurements.

The proposed method uses vehicle input-deflection output measurements system which can measure the location of a vehicle by using Robotic Total Station(RTS) and measures deflection and strain simultaneously. It can acquire a large number of data from multi points. A large number of data can contribute to the development of a reliable FE model. It can update the stiffness-matrix by using static measurements and then update mass-matrix by using natural frequencies of the bridge. In this proposed method, assumption of the mass matrix is not needed.

	Conventional FEMU Approach	Proposed FEMU Approach
Resultant	Update K matrix With assumption on M matrix	Update K matrix and M matrix without assumption on M Matrix
Procedure	<div style="display: flex; align-items: center;"> <div style="border: 1px solid blue; padding: 5px; margin-right: 10px;">Modal Parameters</div> <div style="border: 2px solid red; padding: 5px; background-color: red; color: white; text-align: center;"> Eigen Update <ul style="list-style-type: none"> • Update K matrix without assumption on M matrix </div> </div>	<div style="display: flex; align-items: center;"> <div style="border: 1px solid green; padding: 5px; margin-right: 10px;">Measurements</div> <div style="border: 2px solid red; padding: 5px; background-color: red; color: white; text-align: center;"> Static Update <ul style="list-style-type: none"> • Update K matrix without assumption on M matrix </div> <div style="border: 1px solid blue; padding: 5px; margin-right: 10px;">Modal Parameters</div> <div style="border: 2px solid red; padding: 5px; background-color: red; color: white; text-align: center;"> Eigen Update <ul style="list-style-type: none"> • Update M matrix </div> </div>

Fig. 2 Comparison FEMU approach

3. FIELD EXPERIMENT

For validation of the proposed method, a field experiment has been carried out on the Samseung Bridge (Fig. 3) which is a steel plate-girder bridge with longitudinal length of 40m, width of 12.6m, and consisting of five I-sectional steel girder.



Fig. 3 Samsueng bridge

For measuring the vehicle input – deflection output measurements, a new measurement system was used consisting of a Robotic Total Station (RTS, Fig. 5 (a)), two vision-based deflection sensors (Fig. 5 (b)) and two strain sensors(Fig. 5 (c)). Total station (Leica TS-15) was set up to track a reflector attached on top of the vehicle. A

truck (26.8 ton) was driven at 10 km/h for forward movement and 5 km/h for backward movement over the bridge in three different lanes (Fig. 6), repeatedly 10 times for each lane.

Responses of the bridge when loaded by the truck were measured by using vision-based deflection sensors and strain sensors. Time histories of responses and location of truck are shown in Fig. 7.

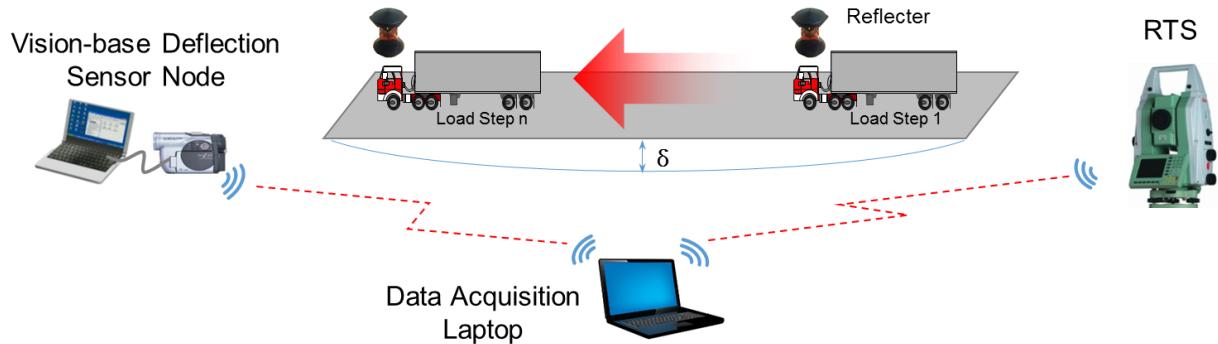


Fig. 4 Measurement system for Vehicle Input/ Deflection Output

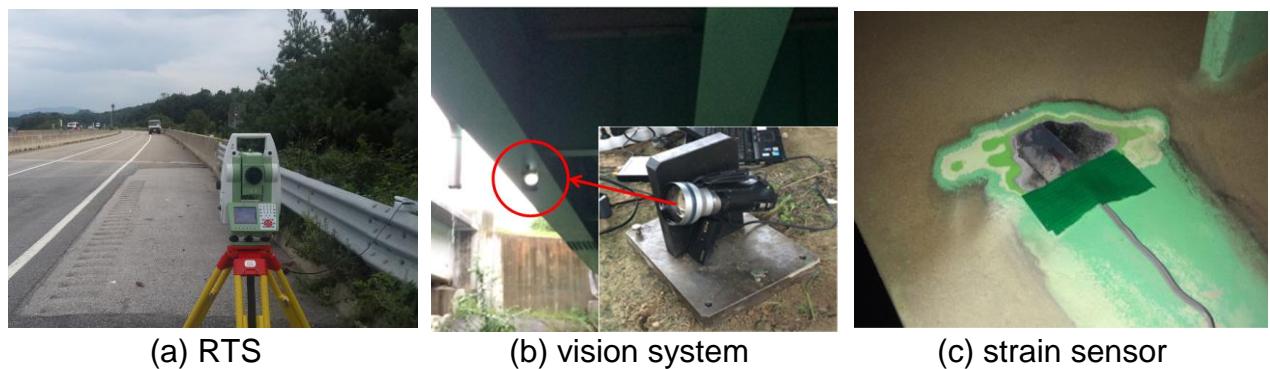


Fig. 5 Measurement equipment

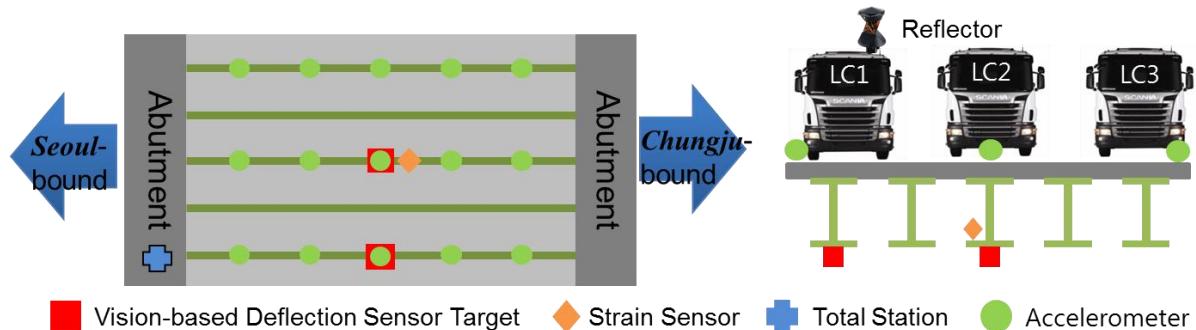


Fig. 6 Sensor array along with vehicle loading detail

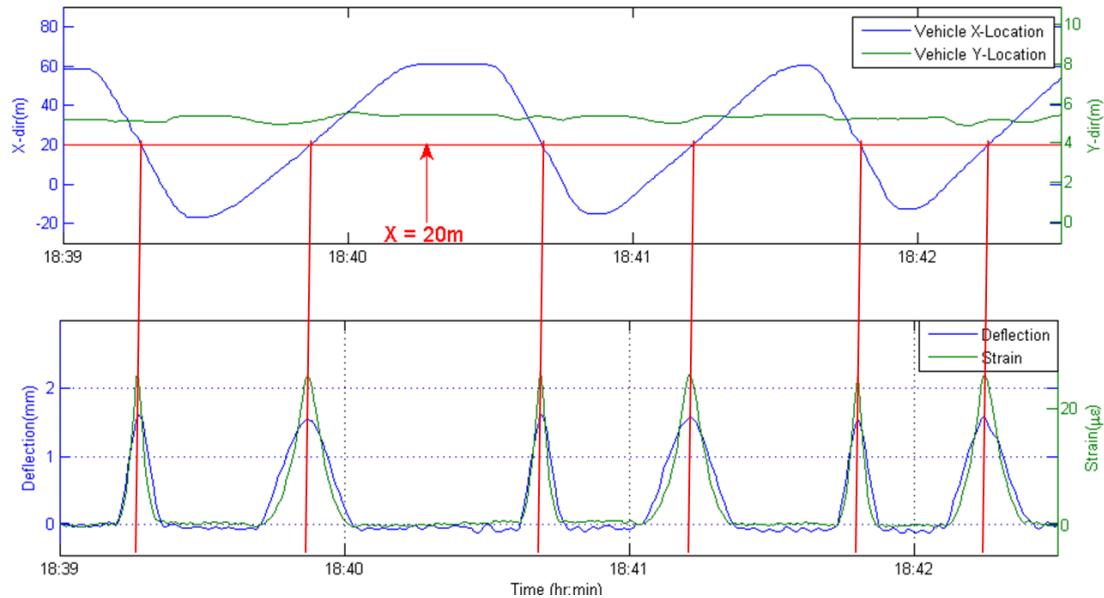


Fig. 7 Time history of Vehicle Input/ Deflection Output for LC2



Fig. 8 Initial FE model

4. MODEL UPDATING by PROPOSED METHOD

4.1 INITIAL FINITE ELEMENT MODEL

Initial FE model of the Samseung Bridge was developed by using ANSYS Mechanical APDL as shown in Fig. 8. Steel girders, slab deck, and some of cross girders were modelled by SHELL181 elements and the other cross beams were modelled by BEAM188. There were 131,266 SHELL181 elements and 608 BEAM188 elements in the model.

Initial FE model was compared to experiment data with analysis result of FE model (Table 1). In the static analysis case, deflection on the internal girder when the truck was loaded on mid-span(1.62mm) is smaller than the static analysis result of FE model(2.95mm). In the dynamic analysis case experiment, measurements are higher than eigen analysis result of FE model. From these results, initial FE model was

developed to be more flexible than the real state of bridge.

4.2 MODEL UPDATING

For model updating equation 1 is used as a cost function. It presents fitness of prediction of updated FE model with experiment measurements.

$$Fitness = \left(1 - \frac{\|y^{\text{exp}} - y^{\text{FEM}}\|}{\|y^{\text{exp}}\|} \right) \times 100\% \quad (1)$$

where, $y^{\text{exp}} = \{y_{1d}^{\text{exp}} \dots y_{nd}^{\text{exp}}, y_{1s}^{\text{exp}} \dots y_{ns}^{\text{exp}}\}$, y_{id}^{exp} , y_{is}^{exp} is deflection and strain when truck located in i-th position. y^{FEM} is consisted of deflection and strain, which calculated by FE model. $\|\cdot\|$ is the 2-norm.

For model updating 50 location of vehicle data, deflection of internal girder and strain of internal girder used for LC2. Young's modulus of the girder(E_{girder}) and Young's modulus of the slab(E_{slab}) were selected as model updating parameters.

Model updating was conducted manually. E_{girder} and E_{slab} were manually adjusted for satisfying fitness of prediction of FE model with experiment measurements over 90%. Updated model updating parameters are higher than initial value (Table 2). Slab was constructed from precast PSC slab and it makes large uncertainty to E_{slab} . From this reason, E_{slab} is increased past the initial value. E_{girder} and boundary condition relate with deflection of bridge. If boundary condition is deteriorated, deflection of bridge is decreased. If E_{girder} is deteriorated, deflection of bridge is increased. In this case, boundary condition was not selected as a model updating parameter and selected E_{girder} is increased. As a reasonable inference, increasing of E_{girder} means deterioration of boundary condition and decreasing deflection of bridge.

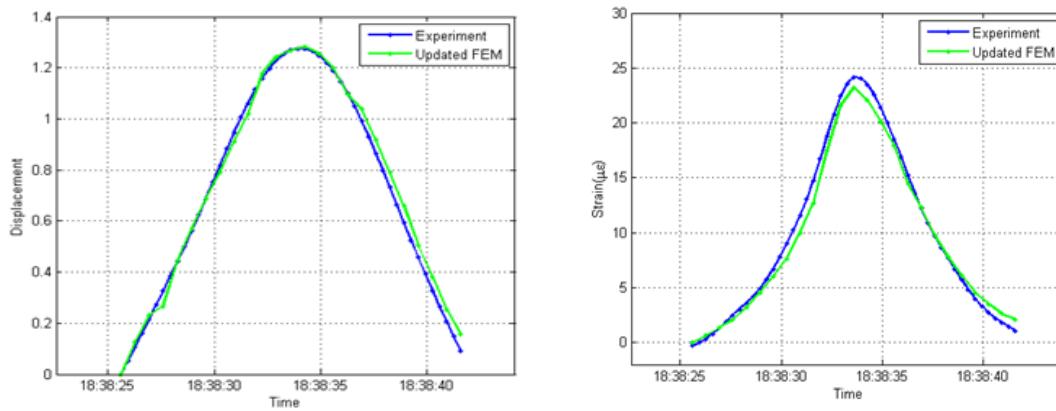
Table 1 Result of Updated FE model

Analysis Case	static analysis : deflection of mid-span on internal girder	modal analysis : 1st bending mode	modal analysis : 1st torsion mode
Experiment (a)	1.62 mm	4.34 Hz	4.81 Hz
Initial FE model (b)	2.95 mm	2.99 Hz	3.87 Hz
Updated FE model (c)	1.84 mm	4.44 Hz	4.70 Hz
Error (a) : (b)	82.10 %	- 31.11 %	19.54 %

Error (a) : (c)	15.43 %	2.30 %	-2.29 %
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Table 2 Result of model updating

Model updating parameter	Initial Value	Updated Value	Variation
E_{girder}	211.60 GPa	221.33 GPa	4.60 % increase
E_{slab}	25.00 GPa	31.85 GPa	27.43 % increase



(a) Deflection (b) Strain

Fig. 9 Predicted Response of Updated FE Model

5. CONCLUSIONS

A new FEM Updating method was proposed to improve current FEM Updating approaches based on modal parameters. The proposed method combines static and dynamic responses to estimate both the stiffness and mass matrices free from any bias of the conventional FEMU method using modal parameters. New vehicle input and static deflection output measurement system has been developed by integrating a RTS, Vision-based deflection sensors and strain sensors, and were successfully applied to field measurements in Samseung Bridge in South Korea. Initial FE model was updated using vehicle input-deflection output measurements. As a result, the updated FE model fits quite successfully to achieve Fitness value of 90% for static responses of bridge. Further investigation considering boundary condition will be carried out for getting a better updated model.

Acknowledgement

This research was supported by a grant(13SCIPA01) from Smart Civil Infrastructure Research Program funded by Ministry of Land, Infrastructure and Transport(MOLIT) of Korea government and Korea Agency for Infrastructure Technology Advancement(KAIA).

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