PARAMETER IDENTIFICATION USING MODEL UPDATING TECHNIQUE FOR HIGH SPEED RAILWAY BRIDGE

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ABSTRACT

A numerical model for an existing bridge should be modified for well reflecting characteristics of the existing bridge. In this study, a numerical model updating method based on univariate search method is introduced. The identification of dynamic characteristics is one of most important part in the process of model updating. And, many measured responses from a large number of measurement points can be helpful to get reliable dynamic characteristics. Therefore, in this study, measurement point roaming method which can be used for a large number of measurement points with a few sensors had been applied for measurement from existing bridges. Cross correlation technique and proper orthogonal decomposition technique have been used for identifying natural frequencies and mode shapes, respectively, with measured signals. After updating of numerical model with introduced model updating method, numerical experiments for dynamic stability analysis have been performed with updated numerical models. As results, it was possible to analyze the dynamic stability when the travel speed is over 400km/h of difficult velocity to be operated on existing bridges.

Keywords: Numerical model updating, High speed railway bridge, Univariate search method, Numerical experiment.

1. INTRODUCTION

An early numerical model updating was developed for directly updating(Baruch and Itzhac 1978). However, the model updating technique based on direct updating method has a weakness to apply to high degree of freedom structure or complicated shape. For surmounting the weakness of direct methods, many repetitive methods based on finite element analysis technique have been proposed. However, there is a weakness of repetitive method which is differential function of characteristic matrix should be prepared in every step. In this study, a model updating technique which does not need to prepare differential function in every step, based on repetitive method is introduced. The usability of introduced model updating method has been evaluated by dynamic stability analysis with updated model by the introduced updating method.

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Meanwhile, precise measurement and reliable analysis should be performed for accurate model updating. For precise measurement, it is need to gather response signals from a large number of measurement points. However, the number of sensors can be limited in a field measurement. Measurement point roaming method can be helpful to solve this problem. For using the measured signals by measurement point roaming method, additional data process could be need because the signals are time synchronized case by case. Cross correlation technique can be useful for identifying more accurate dynamic characteristics from not synchronized signals. Therefore, cross correlated signals was used for identifying natural frequencies and mode shapes by fast Fourier transform and proper orthogonal decomposition technique, respectively. Those identified dynamic characteristics have been used for target values in the updating processes of models which had been constructed based on design drawings and structural calculation reports.

2. FIELD MEASUREMENTS

2.1. Test Bridges

Imgi 2nd Bridge and Maeaji Bridge was selected for test bridges in this study. Imgi 2nd Bridge consists of eleven simply supported PSC box girders of 40 meters. And Maeaji Bridge consists of two continuous PSC box girders of 50 meters. And each span is 25 meters. The test section was selected in consideration with travel speeds and efficiency of measurement. The side views of each bridge are shown in Figure 1.

2.2. Measurement Conditions

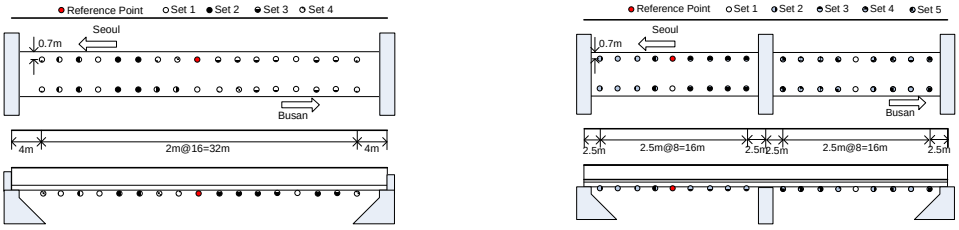
Measurement point roaming method was used for collecting response signals in this study to evaluate accurate dynamic properties of the bridges. Narada system, one of wireless sensing system, was used to easily move sensors from a measuring point to another point. Figure 2 shows Narada WSU(wireless sensing unit) and base station of the wireless sensing system. For precise measurement, the measurement locations for each test had been selected as shown in Figure 3. All of measurement points were located on bottom surface for evading interruption to train running. A reference point which should be needed for data process had been selected for

(a) Imgi 2nd Bridge (b) Maeaji Bridge

Figure 1 : Side views of test bridges

(a) Installed Narada WSD on bridge (b) base station and laptop

Figure 2 : Narada wireless system



(a) Imgi 2nd Bridge (b) Maeaji Bridge

Figure 3 : Measurement points for test bridges

Table 1: Measurement conditions

Conditions		*Imgi 2nd Bridge*	*Maeaji Bridge*
Locations		2nd span, bottom surface	1st & 2nd span, bottom surface
No. of measuring points(sets)		34 points(4)	28 points(5)
System	Sensors	CXL04GP3, ADXL-320(reference point)	
	Data acquisition	Narada system	
Duration		50 seconds	
Sampling rate		200 Hz	
Measured signal		Acceleration response	

the mid-point of a span in each field measurement as shown in Figure 3. Response acceleration signals were collected only when trains were moving to Seoul because of loading characteristic of high speed railway bridges. This limitation of load case could be helpful for numerical analysis. The measurement was performed for 50 seconds including train passing and free vibration terms. And sampling rate was set up as 200 Hz for evading aliasing errors. The measurement conditions for each test are shown in Table 1.

3. EVAULATION OF DYNAMIC CHARACTERISTICS

3.1. Natural frequency evaluation

Cross correlation technique(Clough and Penzien 1993) and fast Fourier transform have been applied for reliable natural frequency evaluation with not synchronized time signals. The same components in two signal are amplified by applying cross correlation technique. Therefore, it can be easier to identify dominant dynamic characteristics using cross correlated signals than using raw signals. The basic cross correlation function is shown in equation (1).

$$R_{xy}(\tau) = \frac{1}{N}\sum_{k=1}^{N} x(k)\cdot y(k+\tau) \tag{1}$$

Here, $x(k)$ and $y(k)$ means measured value at step k in the signals of x and y, respectively. N is the number of data for cross correlation function. And, τ means time interval from step k which can be used as a new time domain for cross correlated signal.

3.2. Estimation of effective span length

Mode shapes have been estimated with correlated signals by using proper orthogonal decomposition(Berkooz et al. 1993). It is possible to estimate mode shapes with cross correlated signals and proper orthogonal decomposition technique even though the raw signals were not time synchronized.

A matrix consisted structural response signals can be expressed as equation (2). The equation (4) can be driven by using the correlation matrix of response signals as expressed in equation (3),.

$$[X]=\begin{bmatrix} x_1(t_1) & x_2(t_1) & \cdots & x_L(t_1) \\ x_1(t_2) & x_2(t_2) & \cdots & x_L(t_2) \\ \vdots & \vdots & \cdots & \vdots \\ x_1(t_N) & x_2(t_N) & \cdots & x_L(t_N) \end{bmatrix}=\left[\{q\}_1\{\phi\}_1^T+\cdots+\{q\}_L\{\phi\}_L^T\right] \tag{2}$$

$$[C]=(1/N)[X]^T[X] \tag{3}$$

$$[C]\{\phi\}_i=\lambda_i\{\phi\}_i \tag{4}$$

In equation (2), $x_l(t_n)$ is measured value on time step n, from a measuring location l and $\{q\}_r$ and $\{\phi\}_r$ means time function and mode shape on measuring point, respectively. In equation (4), eigenvalue λ_l and eigenvector $\{\phi\}_i$ can be calculated because eigenvalue λ_l can be expressed as $(1/N)\{q\}_i^T\{q\}_j$ with modal coordinate $\{q\}_r$. However, even though the mode shapes are estimated, it could be hard to be directly used for target values in model updating process. Because there is difference between the estimated mode shapes with measured signals and calculated mode shapes by finite element analysis programs. Therefore, in this study, the effective span lengths which mean the lengths between x intercepts of mode shape have been used for target values instead of mode shapes. The natural frequencies and effective lengths of mode shapes are shown in Table 2.

Table 2: Estimated target values for model updating from measured responses

Mode	Imgi 2nd Bridge		Maeaji Bridge	
	Natural frequency[Hz]	Effective length of mode shape[m]	Natural frequency[Hz]	Effective length of mode shape[m]
Vertical	4.96	40.75	8.20	25.07
Torsional	25.64	37.64	24.57	26.43

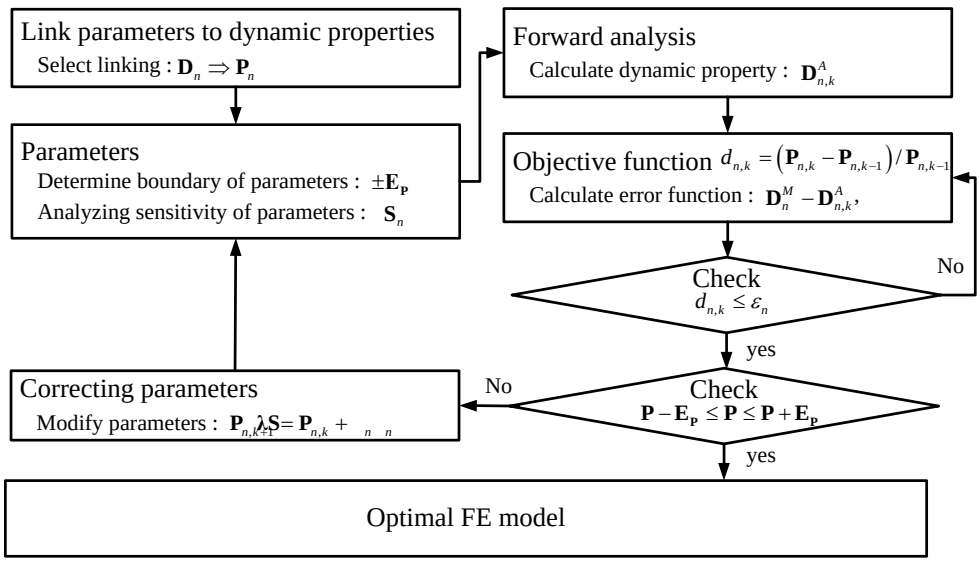


Figure 4 : Model updating algorithm based on univariate search method

4. MODEL UPDATING AND NUMERICAL EXPERIEMENT

4.1. Numerical model updating method based on univariate search method

Univariate search method, one of unconstrained optimization technique, is an optimization method based on one dimensional search method in which only one parameter is updated in a step for improvement of approximate values. In this study, the object function is defined as relative error like equation (5) for evading oscillation phenomenon which can be happened by using multi parameters. The model updating algorithm used in this study is shown in Figure 4.

$$\text{Relative Error } d_k = \frac{P_{n,k} - P_{n,k-1}}{P_{n,k-1}} \tag{5}$$

In the Figure 4, D_n^M means n th dynamic property from measured signals and $D_{n,k}^A$ means analyzed n th dynamic property from k th forward analysis. ε_n is limitation of object function of n th dynamic property and E_P is allowable error for $\lambda_{n,k}$ parameters. $S_{n,k}$ which can be can be defined as equation (6) means the step length of n th parameter on step k. And the search direction of n th parameter on step k can be defined as equation (7).

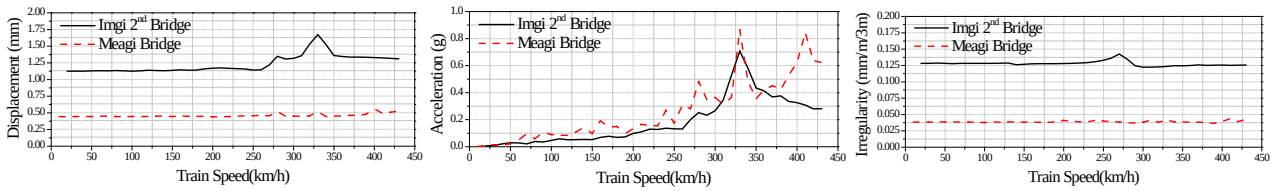
$$\lambda_{n,k} = 1 - \left(\left(\sum_{i=1}^{N} W_i \cdot \left(d_{n,k,i}^A / d_{n,i}^M \right) \right) / \left(\sum_{i=1}^{N} W_i \right) \right) \tag{6}$$

$$S_n = \begin{cases} 1 & (d_{n,k,i}^A - d_{n,k-1,i}^A)/(P_{n,k} - P_{n,k-1}) \geq 0 \\ -1 & \text{Otherwise} \end{cases} \tag{7}$$

In equation (6), (7), $D_{n,k,i}$ means n th dynamic property of i th mode at k th step. And W_i means weight factor of i th mode. In the model updating method based on univariate search method, each parameter should be related with separate target function. Also, the sensitivity of a parameter with a target function related other parameter should be lower than related one. Therefore, the elastic modulus of concrete and the length between support points have been selected for updating parameters of the natural frequencies and effective length of mode shapes, respectively. The relationship is determined by sensitivity analysis with numerical model.

4.2. Numerical experiment

It is hard to evaluate dynamic stability from field experiments with existing bridge because of safety. Therefore, in this study, dynamic stability analysis has been performed with updated numerical models to 430km/h of travel speed. According to Design Guideline for Honam High Speed Railway, the dynamic analysis should be performed to 1.1 times of design speed with 10km/h step. However, in this study, dynamic analysis has been performed to 430km/h, even though the design speeds of target bridges are 350km/h. Three properties as maximum vertical displacement, vertical acceleration on top surface and irregularity of rails have been checked for dynamic stability. The results are shown in Figure 5 and Table 3. The maximum displacements and accelerations were observed when beating frequencies by train were near the first vertical frequencies of bridges. However, the maximum irregularities were occurred when beating frequencies by train were near the first torsional frequencies of bridges.



(a) Max. Vert. Displacement (b) Max. Vert. Acceleration (c) Max. Irregularity

Figure 5 : Results of dynamic stability analysis

Table 3: Limits for dynamic stability and analyzed maximum values

State	*Limit*	*Imgi 2nd Bridge*	*Maeaji Bridge*
Vert. Displacement [mm]	3.33	1.67	0.56
Vert. Acceleration [m/s^2]	4.90	0.69	0.87
Irregularity in the track [mm/m/3m]	1.20	0.14	0.044

5. CONCLUDING REMARKS

In this study, a numerical model updating algorithm based on univarite search method has been introduced and applied to existing high speed railway bridges. The usability of updating method and updated model have been verified by performing dynamic stability analysis with updated numerical model. It could be concluded from the results that it was possible to update numerical model by using introduced model updating method without preparing differential function of matrix. Also, the updated model can be used for numerical experiment. However, the verification of applicability of introduced method for different bridge types is needed because it is verified only with PSC box girder bridges.

6. ACKNOWLEDGMENTS

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