Study on the ambient vibration characteristics by automated estimation of existing bridge dynamic characteristics by ERA/DC method

○ **Md. Rajab ALI**	**Graduate student**	**Student Member**	**Nagasaki University**
Takatoshi OKABAYASHI	**Professor**	**Fellow**	**Nagasaki University**
Toshihiro OKUMATSU	**Research Associate**	**Member**	**Nagasaki University**

1. Introduction:

Execution of vibration tests on bridges is difficult and expensive. On the contrary ambient excitation is freely available but the characteristics of input force remains unknown.In this study it has targeted to observe the effect of ambient vibration characteristics on the estimation accuracy of bridge dynamic characteristics(frequency,damping, and vibration mode). Existing 152 m long Kabashima bridge situated an Nagasaki prefecture, Japan has selected as an object bridge. Multipoint ambient vibration measurement was executed at the same position of the bridge location considering three different ambient condition such as **case-1:**strong wind with random moving vehicle **case-2:**medium wind without moving vehicle **case-3:**strong wind with restricted number of moving vehicle . Vibration characteristics of the bridge has estimated by using ERA/DC method, and the estimation accuracy was observed herein.

2. Realization theory :

Realization problem by stochastic theory is the estimation of coefficient matrices A, B and C from the state equation using Markov parameters, which can be computed from the measured data of free vibration by impulse external force. Based on the interaction of impulse response function and auto correlation function of ambient vibration, stochastic realization methods are proposed to solve matrices A, B, and C from the state equation. In this study ERA/DC(Eigensysten Realization Algorithm with Data Correlation has selected as studied method.

3. Dynamic characteristics estimation:

The eigenvalue analysis of system matrix $\boldsymbol{A}$ generates eigenvalue and eigenmode. Thus $n/2$ independent eigen frequency ω_s and damping h_s could be estimated from the complex conjugate eigenvalue by the equations below

$$\sigma_s = -2h_s\omega_s \tag{1}$$

$$\Omega_s = \sqrt{1-h_s^2\omega^2} \tag{2}$$

Expressing $\overline{\boldsymbol{\Psi}}$ as a mode of measured point, estimation of vibration mode would be established from the relation as below:

$$\overline{\boldsymbol{\Psi}} = \boldsymbol{C\Psi} \tag{3}$$

4. Ambient vibration experiment:

To carry out the ambient vibration measurements on Kabashima Bridge (refers to **Figure 1** and **Table 1**), accelerometers were placed at various locations along the bridge length. Five accelerometers were setup at 25.50 m interval on the girder . The measurement was conducted in different time under three conditions. The first measurement was done with normal traffic flow and comparatively strong wind. The second one was performed with normal wind condition.The third one was conducted with strong windy condition with restricted number of moving vehicle. Sixty Thousands (60,000) data for every channel were observed and recorded in 10 minutes. The acceleration signals is converted from analog to digital by AD converter (DAQ Card), and recorded by the personal computer. The measurement was executed through virtual measurement instrument software LabVIEW. The acceleration signal was processed by off-line using the programming software MATLAB to calculate the dynamic characteristics of bridge.

Figure1: Kabashima bridge

Table 1: Bridge properties

Name	Kabashima Ohashi (NagasakiCity,Japan)
Road name	General prefecture road (Kabashima port line)
Bridge type	Langer truss steel bridge (RC floor)
Year of construction	1985
Length	227m (main span 152m)
Steel weight	677t

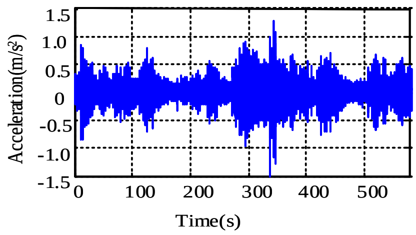

Figure 2: Ambient vibration(case-1)

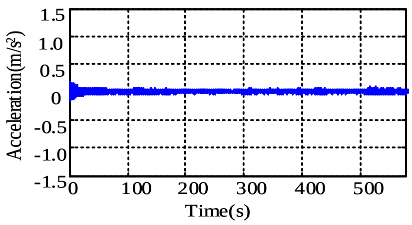

Figure 3: Ambient vibration(case-2)

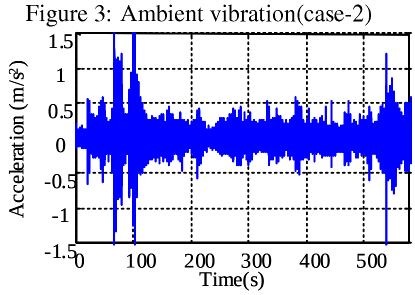

Figure 4: Ambient vibration(case-3)

5. Ambient vibration data and their characteristics:

To execute the experiment three different ambient condition such as **case-1:**strong wind with random moving vehicle **case-2:**medium wind without moving vehicle **case-3:**strong wind with restricted number of moving vehicle was taken in consideration. The recorded ambient vibration from the experiments can be shown in **Figure 2**, **3**, and **4** for case-1, case-2 and case-3 respectively ,which represent the characteristics of measured ambient vibration. Figures for case-1 (refer to Figure 2) reveals that measured data have non-stationary state with higher magnitude , for case-2 (refer to Figure 3) ,the ambient vibration is stationary as the input force is only wind force,Whereas for case-3 (refer to **Fig 4**) ,the ambient vibration is stationary with higher amplitude.

6. Data processing system (Formation of Hankel matrix):

The estimation of frequency using ERA/DC method can be briefly explained here. The size of Hankel matrix was considered as $((5\times55)\times(5\times445))$ and formed by using ambient vibration data of multipoint (5 points) measurement.The number of rows in Hankel matrix was fixed by trial and error method and comparatively large (10 to 12) times of the number of observation point. The column size of Hankel matrix was fixed to 445 blocks. In estimation process, 3000 data were analyzed as continuous ambient vibration for one time and the calculation were repeated for 25 times.

7. Discussion on estimation result:

Figures 5, 6 and **7** are the graphical representation of automatically estimated frequency obtained by ERA/DC method for the data of case-1, case-2 and case-3 respectively. The values of the estimated frequency are presented in **Table 2** for the comparison. The mean frequencies, standard deviations, are compared in the following sections. Deviation of mean estimated value can be used to evaluate the estimation accuracy. The estimation accuracy for lower order frequencies is comparatively high. The figures reveal that the estimation accuracy increase in order of Figure 5, 6 and 7. Figure 7 shows that estimated frequency from 1st to 7th mode order is well arranged , Figure 6 reveals that upto 5^{th} frequency is well arranged .For case-1 (Figure 5) the frequency up to 5^{th} mode is arrange but the accuracy is low. In the same order of estimation accuracy damping can be estimated (refers to **Figure 8**). **Figure 9** represent the average mode of vibration. From the figure 9 we can see that 4th mode is same as 2nd because of the torsional vibration. In general it can be said that for accuracy estimation of dynamic characteristics stationary as well as well excitement (higher amplitude) is necessary.

8. Conslusions:

Dynamic characteristics of existing Kabashima bridge has estimated for the ambient vibration under three different condition.The estimated result leads to the following conclusions

(1) A steady and accuracy estimation of dynamic characteristics is possible for stationary ambient vibration with higher amplitude.

(2) Non-stationary ambient vibration is not suitable for the estimation of dynamic characteristics as it contains the effect of moving vehicle.

Reference: H. Wenzel and D. Pichler:Ambient vibration monitoring, John Wiley and Sons Ltd., 2005

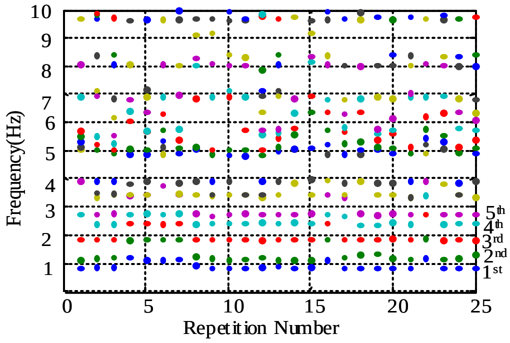

Figure 5: Estimated frequency(case-1)

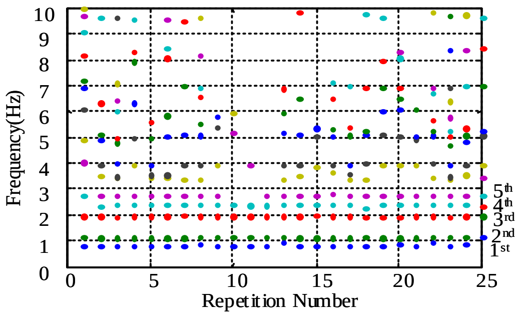

Figure 6: Estimated frequency(case-2)

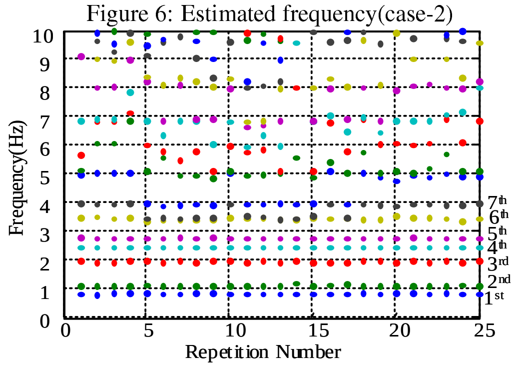

Figure 7: Estimated frequency(case-3)

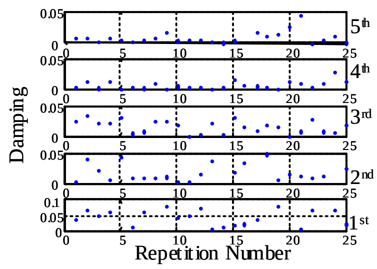

Figure 8: Estimated damping(case-3)

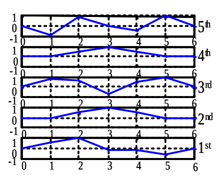

Figure 9: vibration mode (case-3)

Table 2: Estimation accuracy (frequency)

Mode Order	Mean Frequency(Hz)					
	case-1	accuracy	case-2	accuracy	case-3	accuracy
1st	0.914	○	0.85	◎	0.8041	◎
2nd	1.3491	△	1.1567	◎	1.1178	◎
3rd	2.0064	○	1.9576	◎	1.9379	◎
4th	2.5707	○	2.4252	◎	2.4213	◎
5th	3.1141	△	2.9917	△	2.7661	◎
6th	3.8554	△	3.4738	△	3.447	◎
7th	4.3267	△	3.8224	△	3.8016	△

◎:std<0.1 ○: std 0.2 ~ 0.3 △:std >0.3