민감도 분석을 통한 프리스트레스 콘크리트 거더의 유한요소모델 개선

FE-model Update for System Identification of PSC Girder

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Abstract

This paper presents a sensitivity-based finite element (FE)-model update procedure for prestressed concrete (PSC) girder bridge model using vibration test results. Firstly, the stiffness parameters of the structure such as flexural rigidity of concrete and flexural rigidity of tendon are chosen as updating parameters. Next, the numerical frequencies of first two bending modes are calculated using a three-dimensional FE model which is established for the PSC girder. Then, the corresponding experimental frequencies which are obtained from forced vibration tests are selected. In order to perform the model update, the eigensensitivity-based method is employed. Finally, the effect of prestress-loss on the stiffness parameters is evaluated.

keywords : finite element, model update, eigensensitivity analysis, PSC girder, prestress-loss

1. Introduction

In structural engineering analysis and design, finite element (FE) method is a powerful and useful tool to simulate the behavior of real structure. A number of FE-model update methods in structural dynamics have been proposed (Friswell and Mottershead, 1995; Brownjohn et al., 2001; Jaishi and Ren, 2005). Based on the previous works, in this study, a sensitivity-based FE-model update procedure for PSC girder bridge model using vibration test results is presented. Firstly, the stiffness parameters of the structure such as flexural rigidity of concrete and flexural rigidity of tendon are chosen as updating parameters. Secondly, the numerical frequencies of first two bending modes are calculated using a three-dimensional FE model which is established for the PSC girder. Thirdly, the corresponding experimental frequencies which are obtained from forced vibration tests are selected. Finally, the eigensensitivity-based method is employed to perform the model update. Based on updated results, the effect of prestress-loss on the stiffness parameters is evaluated.

2. Eigensensitivity-based FE-Model Update Method

Kim and Stubbs (1995, 1996) proposed an eigensensitivity-based system identification method to develop baseline modal model of structure. Suppose k_j^* is the unknown stiffness of the j^{th} member of the structure for which M eigenvalues are known. Also, suppose k_j is a known stiffness of the j^{th} member

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of a FE model for which the corresponding set of M eigenvalues are known. Then, relative to the FE model, the fractional stiffness change of the j^{th} member of the structure, $\alpha_j \geq -1$, and the stiffnesses are related according to the following equation

$$k_j^* = k_j(1+\alpha_j) \tag{1}$$

The fractional stiffness change of NE members may be obtained using the following equation

$$\alpha = F^{-1}Z \tag{2}$$

where α is a $NE\times 1$ matrix containing the fractional changes in stiffnesses between the FE model and the structure; Z is a $M\times 1$ matrix containing the fractional changes in eigenvalues between two systems; and F is a $M\times NE$ sensitivity matrix relating the fractional changes in stiffnesses to the fractional changes in eigenvalues. Using the above theory as a basis, the iterative algorithm was proposed to identify a given structure.

3. Forced Vibration Test

A dynamic test of the laboratory-scale post-tension PSC girder was performed to determine the natural frequencies. The schematic of the test structure is shown in Fig. 1. For acceleration measurement, a type of ICP accelerometer, PCB 393B04, was used. Impact forces were applied to the PSC girder by dropping a hammer. The dynamic response in vertical direction was measured by accelerometer with sampling frequency of 300 Hz. Then, the fast Fourier transform (FFT) algorithm was employed to transform the time-history response data to frequency domain. The prestress force was applied to the test structure up to 5 different prestress cases (i.e., PS1-PS5). The minimum and maximum prestress forces were set to 39.2 kN and 117.7 kN, respectively.

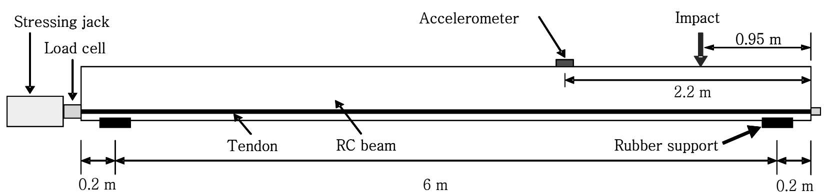


Fig. 1 Dynamic test on PSC girder

4. Initial FE Model and Updating Parameters

In this study, SAP2000, a structural analysis and design software, is used to model the PSC girder. The girder is constructed by a 3-D FE model using solid elements. The dimensions of the model are the same as the real structure. For the boundary conditions, spring restraints are assigned at the supports (Fig. 2). The initial parameters of the model are assigned as follows: for the concrete, elastic modulus is 2×10^{10} N/m^2, second moment of area is 0.005 m^4, mass density is 2500 kg/m^3, Poisson's ratio is 0.2; for the tendon, elastic modulus is 3×10^{11} N/m^2, second moment of area is 1.333×10^{-8} m^4, mass density is 7850 kg/m^3, Poisson's ratio is 0.3; and the stiffness of springs are assumed as 10^9 N/m.

In the FE-model update procedure, the choice of parameters is an important step. For the present PSC girder, the potential parameters may include flexural rigidity of concrete (E_cI_c), flexural rigidity of tendon (E_pI_p), flexural rigidity (E_gI_g) and mass density (ρ_g) of two groups at the ends of the girder, vertical spring stiffness (k_v) and horizontal spring stiffness (k_h) at the supports (Fig. 3). Two parameters, E_gI_g

and ρ_g, are considered due to the influence of anchor plates. Based on the initial FE model, the eigenvalue sensitivity analysis was carried out for six potential parameters. The analytical results are given in Table 1 and shown in Fig. 4. It can be seen that E_cI_c is the most sensitive parameter for both mode 1 and mode 2. And E_pI_p has relative influence on two vibration modes while the other parameters do not seem to affect. For this reason, two parameters, E_cI_c and E_pI_p, were chosen for updating the first two bending frequencies of PSC girder.

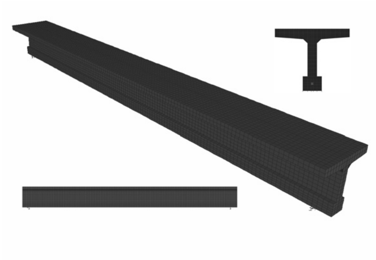


Fig. 2 Initial FE model

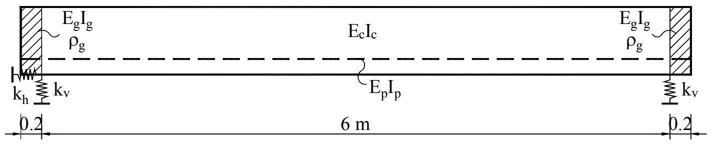


Fig. 3 Potential updated parameters

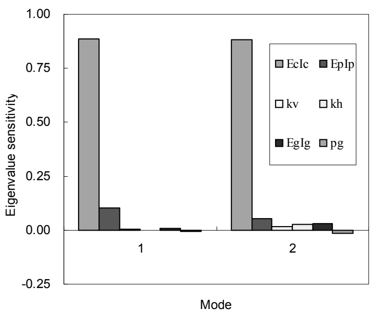


Fig. 4 Eigenvalue sensitivities

Table 1 Eigenvalue sensitivities of potential parameters

Mode number	Sensitivities					
	E_cI_c	E_pI_p	k_v	k_h	E_gI_g	ρ_g
1	0.8855	0.1039	0.0029	0.0007	0.0099	-0.0066
2	0.8817	0.0537	0.0150	0.0268	0.0328	-0.0136

Table 2 Change of updated parameters

Updated parameter	Iteration					
	Initial	1st	2nd	3rd	4th	5th
$E_cI_c \times 10^8$(Nm^2)	0.98	1.08	1.06	1.05	1.05	1.06
$E_pI_p \times 10^2$(Nm^2)	40.00	4.00	2.00	1.48	1.40	1.35

Table 3 Value of frequencies for 5 iterations

Mode	Updated frequencies (Hz)						Target
	Initial	1st	2nd	3rd	4th	5th	
1	23.65	23.54	23.30	23.10	23.17	23.21	23.08
2	97.77	99.39	98.51	97.76	98.02	98.17	98.73

5. FE-Model Update

After selection of responses and parameters, an iterative procedure was carried out for model update. The identification results for prestress case PS1, using the first two bending frequencies and 5 iterations, are given in Table 2 and Table 3. After only 5 iterations, the identified frequencies are within less than 0.6% of the values for the target structure. The updated results for 5 prestress cases, PS1-PS5, are also summarized in Table 4. In general, the differences between the measured and updated frequencies are less than 2%. Fig. 5 shows the relative change in flexural rigidity of concrete and tendon. These values are the fraction changes in flexural rigidity between prestress cases PS1-PS5 and prestress case PS1. The updated results for PSC girder show that as the prestress force increases, the flexural rigidity of concrete and tendon increases. Due to as the prestress force increases, more initial microcracks caused by shrinkage closes, and the concrete becomes more hardening. Based on the linear regression analysis, two equations were established to predict the changes of flexural rigidity according to the prestress force for post-cracking stage of the present PSC girder as follows

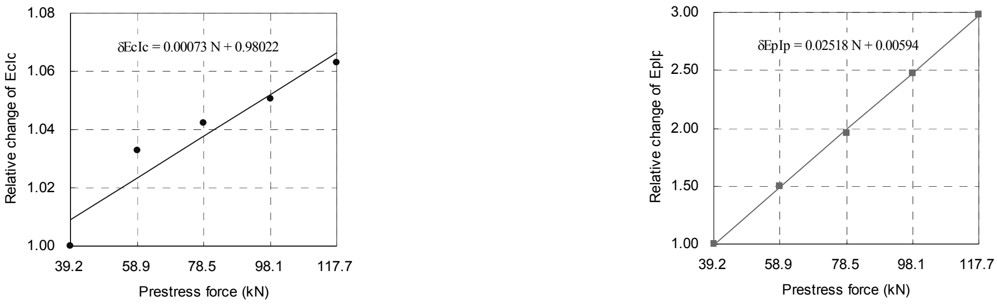
$$\delta E_cI_c = 0.00073N + 0.98022 \quad (3)$$

$$\delta E_pI_p = 0.02518N + 0.00594 \quad (4)$$

where E_cI_c, E_pI_p are the relative change in flexural rigidity of concrete and tendon which compares with prestress case PS1, respectively; and N is the value of prestress force (kN).

Table 4 Updated results for 5 prestress cases

Prestress case	N (kN)	$E_cI_c\times10^8$ (Nm^2)	$E_pI_p\times10^2$ (Nm^2)	Relative change		Updated frequency (Hz)		Measured frequency (Hz)		Error (%)	
				E_cI_c	E_pI_p	Mode 1	Mode 2	Mode 1	Mode 2	Mode 1	Mode 2
PS1	39.2	1.06	1.35	1.00	1.00	23.21	98.17	23.08	98.73	-0.55	0.57
PS2	58.9	1.09	2.01	1.03	1.03	23.60	99.72	23.23	101.39	-1.60	1.64
PS3	78.5	1.10	2.64	1.04	1.04	23.73	100.20	23.39	101.65	-1.44	1.43
PS4	98.1	1.11	3.33	1.05	1.05	23.84	100.63	23.60	101.70	-1.04	1.05
PS5	117.7	1.12	4.01	1.06	1.06	24.01	101.25	23.72	102.54	-1.21	1.26



(a) Concrete (b) Tendon

Fig. 5 Relative change in flexural rigidity of concrete and tendon due to prestress force

6. Conclusion

In this study, an eigensensitivity-based FE-model update approach for PSC girder bridge model using vibration test results was presented. Firstly, the numerical frequencies of first two bending modes were calculated using the FE model which was established for the PSC girder. And, from initial FE model, the sensitivities of six potential parameters were analyzed in order to choose the proper parameters for adjustment. As a result, flexural rigidity of concrete and tendon were chosen as updating parameters. Next, the corresponding experimental frequencies which were obtained from forced vibration tests were selected. Then, the eigensensitivity-based method was employed to perform the model update for 5 prestress cases. The differences between the measured and updated frequencies were generally less than 2%. Finally, the effect of prestress-loss on the stiffness parameters is evaluated.

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