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Finite Element Model Updating Based on Field Quasi-static Generalized Influence Line and Its Bridge Engineering Application

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Abstract

Finite element model updating is the important foundation of structural damage detection, condition assessment for engineering structure. A new method for finite element model updating based on the quasi-static generalized influence line (QSGIL) residual objection is presented to update the finite element model in order to improve the quality of finite element algorithm. The experimental study shows that the method can efficiently update the finite element model.

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Keywords: Finite element model updating; Quasi-static generalized influence line (QSGIL); Field test;

1. Introduction

The finite element model (FEM) updating is essentially a parameter estimation technique [1], based on updating uncertain parameters to get reasonable agreement between the experimental measured model and the initial finite element model. And then the updated FEM can be used to further computation and analysis, even damage detection [2]. Especially, the approach is widely popular in the mechanical engineering, aerospace engineering, et al. They focus mainly on the application of the dynamical parameters including the mode shapes and the frequency response functions, in the finite element model

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updating process [3]. On the other hand, the static properties of structure are also widely studied, this is because that the static parameters are more amenable to the modeling of complex structures. M.R.Banan, et al. plays a lot of attention to the displacements response [4-5], the strain error also excites lots of attention [6-7]. The results demonstrate that for increasing the amount of information, FEM updating become more and more effective. Recently, the application to the static influence line is also attached importance to, which is quite useful to determine worst-case locations of live loads, especially, for bridge design. However, the field influence line becomes more and more important, because of its adequate effective and accurate information about structures. Guangwu Tang, et al. makes full use of multi-objective method containing natural frequencies and static influence line to update the initial finite element model. The technique can reduce the effect of measurement errors on the updating FEM, and even can ameliorate the boundary condition [8]. Interestingly, the static influence line and its sensitivity index are successfully applied to the single damage-damage, and even multi-damage detection, which shows very sensitivity to the damage zone [9-10].

The present study is to further develop a practical and useful approach on finite element model updating based on the field quasi-static generalized influence line. The basic theory of quasi-static generalized influence line is reviewed, and then verified by the model experiments.

2. Theory

Firstly, the QSGIL is shortly reviewed. The design influence line is mainly brought up to handle the design of beam-like structure, such as the bridge, bridge crane, etc. And then the field influence line concept is gradually introduced in the field load testing of bridge. In the field test, the truck moves as slowly as possible along the longitudinal axle for decreasing the dynamical effect, i.e., quasi-static loading process. In the field test, the load isn’t an unit load, but a two-axle truck or other loading methods, and the response signal varies with the time, but not the displacement of the load which needs to be acquired, simultaneously, that is to say, the field influence line is more general than the design influence line. So the field influence line is defined as the quasi-static generalized influence line, QSGIL for short. The acquisition system for it has been developed in the past three years [10]. In a word, the present method is essentially ‘one-point continuous excitation, one (multi)-point measurement’, however, the previous approach is focused on ‘one (multi)-point excitation, multi-point measurement’.

The finite element model updating is essentially a parameter estimation technique using all kinds of algorithms, based on updating uncertain parameters to get reasonable agreement between the experimental measured model and the initial finite element model.

The updating function is the differences between the measured influence line and calculated influence line, Eq. (1):

$$F_i(x) = \sum_{k=1}^{N} \gamma_k \sum_{i=1}^{M} \left( \frac{Z_{mk} - \eta Z_{ik}}{Z_k} \right)$$

Where, \(N\) is the total number of influence line test point; \(M\) represents the total number of load step; \(Z_{mk}\) and \(Z_{ik}\) represent the measured and calculated influence line, respectively; \(\gamma_i\) represents the weight factor of the \(i\)th test point, \(\sum_{i} \gamma_i = 1\), also indicates the different contribution to the objection function.

The uncertain properties of the initial finite element model are mainly selected as updating parameters, for example, the Young’s modulus \(E\) and the boundary conditions. And it is necessary to constrain the updating parameters for the practical engineering purposes and computational aspects, as follows

$$x_i^{\min} \leq x_i \leq x_i^{\max}, i = 1,2,\cdots,n$$

(2)
Where $x^l$ and $x^u$ represents the low and upper limits; $n$ is the total number of the constraint condition.

Finally, the above finite element model updating can be transformed to a classical constrained optimization problem, which has been successfully resolved in the past years. In the present updating method, the iterative process has been efficaciously fulfilled using the sequential unconstrained minimization technique (SUMT) and Powell's method.

3. Model experiment study

The applicability of the present methods in the damaged model is discussed in the section. The damages are simulated on three beams by different geometrical rectangular groove to illustrate the main idea, which induces local changes of bending stiffness $EI$ at the damage zone, sketched in Fig. 1. The perfect model without damage is used to compare with others, and in damaged model B, there are two damaged zones, with the same damage 30.0%, and in the damage model C, the left damaged zone is the same as that of the damage model B, however, the right damaged zone near the midspan point M with damage extent 15.0%, in Fig. 1. The Young’s modulus are 2.67×10^3 MPa.

In the experimental test program, the four beams are respectively subjected to the concentrated force to produce the quasi-static generalized deflection influence line of the midspan point M, which are extracted by deflection measuring apparatus located at the point M. Of course, the strain influence line would be measured if the strain gauges at the cross section of the beam were applied. Note that the load steps aren’t continuously moved on the central longitudinal axis of these beams, but uniform and discrete space for the practical operation, due to the laboratory condition.

The original test data has been filtered using the signal analysis system, and then the displacement of undamaged and damaged beam is obtained as shown in Fig. 2. Both of the minimal deflection values of damaged models derives from that of perfect model, because of the decrease in the whole rigidity of damaged model B and C, which gets agreement with the analytical results [9].

In the matter of the 2-D beam element without regard to the axial effect, different geometrical rectangular groove is equivalent to the decrease of the moment of inertia, and the grooves are simulated by the equivalent bending rigidity, further the equivalent bending stiffness has been normalized by the
initial bending stiffness and chosen as the updating parameters. The parameters of the perfect section are regard as the initial iterative value. The residual error, between the measured and calculated deflection about the point M, is certainly served as the objection for the updating method. In addition, it is necessary that the constraint conditions are settled for the practical physical modal and the stability of algorithm.

![Graph showing deflection of midspan point M for experimental model A, B, and C](image1)

Fig. 2. Deflection of the midspan point M for the experimental model A, B and C

![Graph comparing initial, updated, and measured influence lines for model B and model C](image2)

Fig. 3. Comparison of the initial, updated and measured influence lines for model B and model C

| Damaged zone            | Measured value $EI$ (Nm²) | Updating value $EI$ (Nm²) | Error (%) |
|-------------------------|---------------------------|---------------------------|-----------|
| Left side of model B    | 23.66                     | 23.40                     | -1.10     |
| Right side of model B   | 23.66                     | 23.53                     | -0.56     |
| Left side of model C    | 23.66                     | 23.21                     | -1.94     |
| Right side of model C   | 28.72                     | 28.68                     | -0.17     |
All of the initial, updated and measured influence lines of the damaged model B and C are shown in Fig. 3. In the Table 1, the initial and updated values of model B and C are given. Although both of the updated influence line for the model B and C derive from the measured influence, the maximum absolute error between the measured and updated parameters is below 2.0%, that is to say, the updated values very approach to the measured values. The results demonstrate the updated finite element is very fit for the experimental model and it is possible that the present updating method can be adopted in the practical engineering, especially, for the bridge engineering.

4. Conclusion

In this paper, the field quasi-static generalized influence line (QSGIL) is used to update the finite element model of the experiment sample. The experimental study shows that the present method can efficiently update the finite element model, even can be used to detect the extent of the damage. For the practical fact, the weight factor $\gamma$ is introduced, and the practical iterative algorithm is also adopted. Therefore, it is possible to use the present method to validate the uncertain factor of the finite element model. In addition, base on the field QSGIL, the updating finite element model can be applied to assess the condition and loading-carrying capacity of structure will be reported in the reference [10]. However, there is still a lot of effect on the numerical simulation, need to be further study. It is necessary to further confirm all kinds of the uncertain factors, and to develop the practical and fast iterative algorithm for the more and more large and complex structure.

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References

[1] A.Teughels, G.D.Roeck. Damage assessment of the Z24 bridge by FE modal updating.Key engineering materials 2004;245/246:19-26.

[2] C.Farrar, D.Jauregai. Damage detection algorithms applied to experimental and numerical modal data from the I-40 bridge,1996 technical report, LA-1304-Ms, Los Alamos, National Laboratory.

[3] E.Mottershead, M.I.Friwell. Finite element model updating in structural dynamics: a survey. J Sound Vib 1993;167(2):347-375.

[4] M.R.Banan, M.R.Banan, K.D.Hjelmstad. Parameter estimation of structures from static response. I: computational aspects. J Struct Engng 1994;120(11):3243-3258.

[5] M.R.Banan, M.R.Banan, K.D.Hjelmstad. Parameter estimation of structures from static response. I: numerical simulation aspects. J Struct Engng 1994;120(11):3259-3283.

[6] M. Sanayei, M.J.Saletnik. Parameter estimation of structures from static strain measurements. I- formulation. J Struct Engng 1996;122(5):555-562.

[7] M. Sanayei, M.J.Saletnik. Parameter estimation of structures from static strain measurements. I- error sensitivity analysis. J Struct Engng 1996;122(5):563-572.

[8] Tang Guang-wu, Liao Jingbo, Zhao Yan. Finite element model updating based on dynamic and static measurements using multi-objective optimization, J Chongqing University (national science edition)2007; 30:131-133,145.[in Chinese]
[9] Guangwu Tang, Liao Jingbo, Zhao Yan, Kou Xiana. A Response Profile Approach to Damage Diagnosis. The 6th International Conference on Vibration Engineering. Dalian: Dalian University of Technology Press, 2008.

[10] TANG Guangwu, LIAO Jingbo, Zhao Yan, et al. Project summary report of technological study on bridge vibration testing technique and its application. West-China communications Construction science & technology project, Chongqing Communications Research & Design Institute, Chongqing, 2009.