PROBABILITY-BASED UPDATING FOR NONLINEAR MATERIAL CONSTITUTIVE MODELS OF A STEEL-CONCRETE COMPOSITE BRIDGE

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1. INTRODUCTION

In the next 20 years, the proportion of bridges in Japan built over 50 years ago will increase at an accelerating pace. Therefore, it is urgent to develop an effective method to evaluate the soundness of these aged bridges quantitatively. For many engineering considerations, it is desirable to effectively obtain a validated finite element model that can be considered for several analysis purposes especially bridge health monitoring and inspection. The basic requirements of validated FE models are that the uncertainties of the model are reduced to a minimum and the simulation results fit well with measurements. Unlike simple model calibration, data-driven model updates provide a beneficial way to obtain validated models.

In this paper, a two-span steel-concrete composite girder was tested by static loading to collect load-deflection data for elastic and plastic stress states. A three-dimensional finite element (FE) model was established using Abaqus to simulate the above static loading test. Nonlinear constitutive models of concrete and steel were adopted to describe the stress-strain behavior in response to applied loads. The probability-based model updating was driven by this FE model to infer the posterior joint probability density function (PDF) for the parameters of the nonlinear material constitutive models.

2. BAYESIAN UPDATING WITH TMCMC

Given a forward model of a physical system *M*, uncertain model parameter vector $\boldsymbol{\theta} \in \boldsymbol{R}^{N_\theta}$, and fixed model parameter vector $\boldsymbol{x}$, the system output vector with noise can be expressed as:

$$\boldsymbol{D} = M(\boldsymbol{x}, \boldsymbol{\theta}) + \boldsymbol{e} \tag{1}$$

in which $\boldsymbol{e} \in \boldsymbol{R}^{N_d}$ denotes the error term that is caused by measurement errors and model uncertainties [1].

When a set of independent observations becomes available, the posterior distribution of the parameters of interest can be inferred using Bayes' theorem.

$$P(\boldsymbol{\theta}|\boldsymbol{D}) = \frac{P(\boldsymbol{D}|\boldsymbol{\theta}) \cdot P(\boldsymbol{\theta})}{P(\boldsymbol{D})} \tag{2}$$

where $P(\boldsymbol{D})$ is the evidence of system response $\boldsymbol{D}$, and $P(\boldsymbol{D}) = \int P(\boldsymbol{D}|\boldsymbol{\theta})\,P(\boldsymbol{\theta})d\boldsymbol{\theta}$ $P(\boldsymbol{\theta})$ is the prior PDF $P(\boldsymbol{D}|\boldsymbol{\theta})$ is the likelihood function.

In this paper, the likelihood function for model updating is given as follows [2].

$$P(\boldsymbol{D}|\boldsymbol{\theta}) = c_g e^{-J_g(\boldsymbol{\theta})/2\sigma^2} \tag{3}$$

where $J_g(\boldsymbol{\theta}) = \sum_{i=1}^{N_s}\sum_{j=1}^{N_d}\left(1 - \frac{\delta_{i,j}^{FEM}(\boldsymbol{\theta})}{\delta_{i,j}^{Test}}\right)^2$; $\delta_{i,j}^{FEM}(\boldsymbol{\theta})$ stands for the deflection under an uncertain parameter vector $\boldsymbol{\theta}$ obtained from the FE model and $\delta_{i,j}^{Test}$ denotes the measured one; N_s is the number of sensors, N_d is the number of data points for a load-deflection curve; $\boldsymbol{\sigma}^2$ denotes the variance of Gaussian distribution assumed to quantify errors; c_g stands for a normalized constant.

3. FINITE ELEMENT MODEL

As shown in Fig. 1, the experiment bridge consists of two unequal spans, labeled long span and short span, respectively. Concentrated loads are applied using 4 hydraulic jacks and deflection data are collected by linear variable differential transformers (LVDTs). In the FE model, the steel girder and stiffeners are modeled using shell elements, and the concrete slab is modeled using solid elements. The shear studs and plan bracings are modeled using spring elements and beam elements, respectively.

4. MODEL UPDATING

4.1 Sensitive parameters

Based on the results of sensitivity analysis, the tensile strength of concrete f_{t0}, fracture energy of concrete G_f, and yield strength of steel f_{sy} are selected as the parameters to be updated.

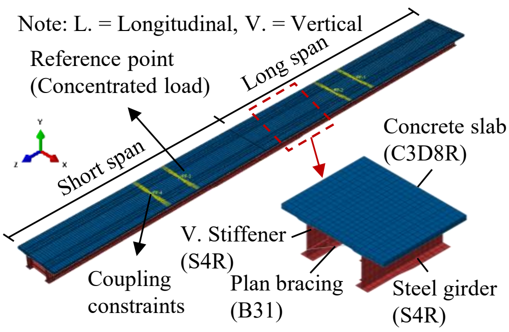

Fig. 1 Experimental setup and FE model.

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Fig. 2 presents the marginal PDF approximation of updated model parameters. The horizontal axis represents the ratio of the updated parameter value to the initial value. It is noted that the updated result showed the tensile strength of concrete was reduced by around 34.5% of the initial one. Fig. 3 shows the updated nonlinear constitutive models of concrete and steel based on the most probable value (MPV) in Fig. 2. In the legend, “initial” and “updated” denote simulation results using initial and updated parameter values respectively.

4.2 Updated load-deflection curves

The load-deflection curve from FEA with the updated FE model is well comparable with the measured one as shown in Fig. 4 while that from the initial FE model failed to fit the measured one, especially in the nonlinear region. As shown in Fig. 4, the scatter plot on the left side of the load-deflection curve is the relative error between the measured deflection and the simulated deflection using updated model parameters corresponding to each level of load. The red-filled area indicates that the relative error is less than or equal to ±10%.

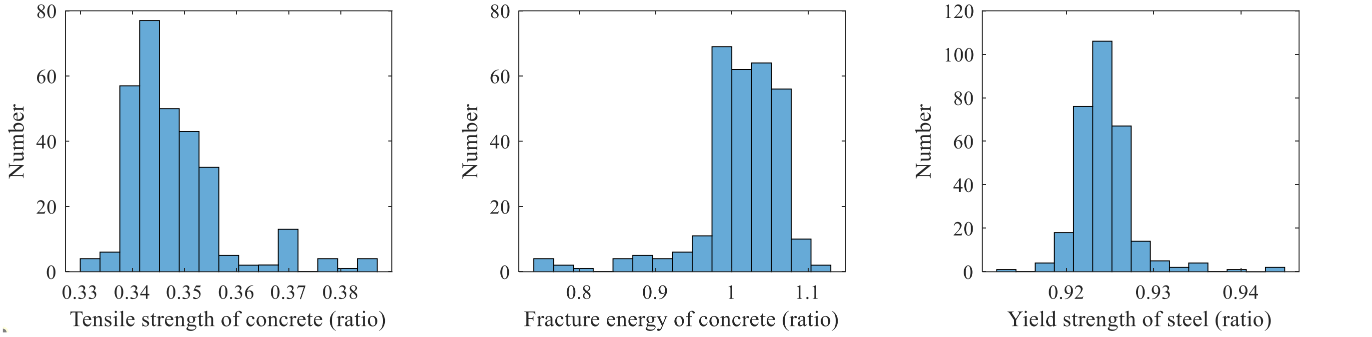
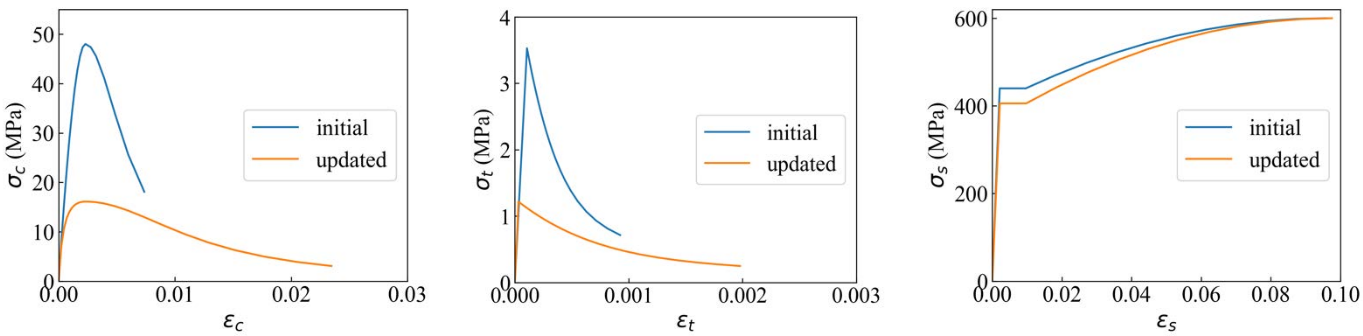
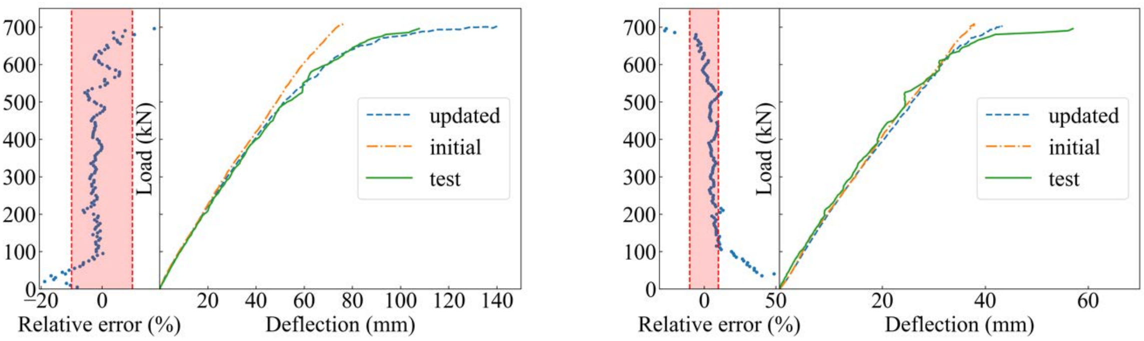


Fig. 2 Marginal PDF of updated model parameters.



(a) compressive behavior of concrete (b) tensile behavior of concrete (c) steel

Fig. 3 Updated material constitutive models.



(a) mid-span of long span (b) mid-span of short span

Fig. 4 Load-deflection curves.

5. CONCLUSIONS

In this study, parameters for the nonlinear material constitutive models of a continuous steel-concrete composite girder are updated based on structural responses measured from the static loading test. After model updating, the error between the measured deflection and the simulated deflection using the updated FE model decreased significantly. The updated FE model can be used for structural performance assessment.

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