Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(11) (2021) 683-686
DOI: 10.22060/ceej.2019.16440.6229

Optimization of concrete tension stiffening model based on layered nonlinear analysis of FRP – RC beams

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ABSTRACT: Tension stiffening effect, which is due to participation of concrete in resisting tension between cracks, results in the reduction of strains of reinforced concrete member relative to pure bars. In some researches, this effect was involved at strain – stress behavior of concrete after cracking that few researches investigated FRP reinforced concrete. In Present investigation, comparison of experimental data with results of layered nonlinear analysis of wide collection FRP-reinforced concrete beams relative to prior researches was used for extracting of concrete strain – stress after cracking. The resulting model unlike previous models was developed for all type of FRP bars. The constants of model are obtained from optimization method based on genetic. 78 curves from 87 curves of FRP – reinforced concrete beams under four-point bending are used for deriving of model coefficients and the others are used for investigating of optimal model. Furthermore, 20 percent of load – deflection data of 78 beams are also randomly selected for controlling of optimal model instead of developing of model. The average natural logarithm of experimental/calculated deflection ratios for randomly selected data by applying initial model and optimal model is 1.0457 and 0.2668, respectively. According to ideal value of zero for natural logarithm of experimental/calculated deflection ratio, applying optimal model has improved this statistical parameter by 74 percent. Responses of nonlinear analysis by using initial model and optimized model are compared with those of code relations.

Review History:

Received: 2019-05-28
Revised: 2019-08-29
Accepted: 2019-11-05
Available Online: 2021-11-18

Keywords:

deflection
Tension stiffening
FRP bars
Nonlinear analysis
Optimization

1. INTRODUCTION

Due to the presence of cracks, the flexural rigidity of a cracked reinforced concrete beam is less than the flexural stiffness of an uncracked reinforced concrete beam, however in the tension zones of the section, the concrete in contact with the reinforcing bars between the cracks by transferring the bonding force from reinforcing bars to concrete is capable of withstanding a certain level of tensile stress and contributes to the flexural rigidity of the beam. This phenomenon is called tension stiffening [1]. tension stiffening relationships can be used to obtain the stress-strain response of concrete after cracking [2]. In this study, section analysis by finite layer approach is used to analyze a number of simple supported beams under four-point bending that their experimental load-deflection curves are available and one of the proposed models for tensile behavior of reinforced concrete with FRP bars was investigated and its parameters was obtained based on minimizing difference between experimental and analytical results. The investigation is conducted in the service load range because the deflection limitation is important in serviceability conditions.

2. PROPOSED MODEL

In this research, the model proposed by Hsu and Zhu (2002) [3] is chosen because of its simplicity and feasibility for all considered beams with regard to their given properties. In this model, two parameters *a* and *b*, according to Eq. (1), are used to calibrate the model using the experimental results of FRP reinforced concrete beams.

$$f_{ct} = E_c\, \varepsilon_t \qquad (\varepsilon_t \le \varepsilon_{cr})$$
$$f_{ct} = a f_{cr} / \left(\varepsilon_t / \varepsilon_{cr}\right)^b \qquad (\varepsilon_t > \varepsilon_{cr}) \qquad (1)$$

Where f_{ct}, ε_t, f_{cr} and ε_{cr} are tensile stress, tensile strain, cracking stress and cracking strain, respectively.

3. METHODOLOGY

One of the applications of the tension stiffening models is the calculation of concrete beam deflection using section analysis by finite layer approach. The method used to predict the bending behavior of reinforced concrete beam sections reinforced with steel and FRP bars is an incremental-iterative technique with secant stiffness formulation [4]. In this method, the moment-curvature relation of section is first calculated, then the nonlinear load – deflection response of beam is formulated by using second moment area theorem.

The stress-strain behavior of reinforcing steel is assumed

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Table 1. Initial and optimized values of model parameters

Method	Parameter	
	a	b
Hsu & Zhu (2002)[3]	1	0.4
Values obtained from optimization	0.142	0.274

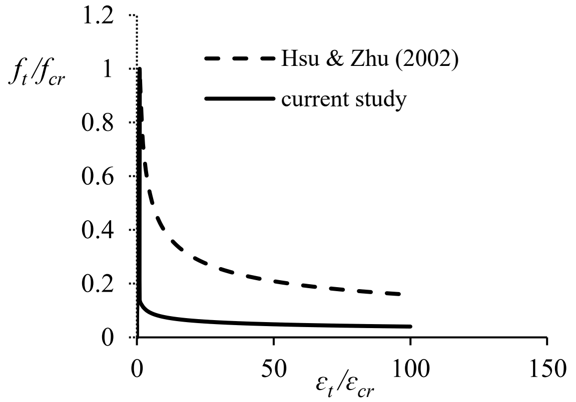

Fig. 1. Normalized tension-stiffening curves with initial parameters [3] and Optimized parameters (current study)

to be bilinear, and The corresponding behavior for FRP bars is considered to be linear up to brittle failure, furthermore the parabolic curve obtained by Hognestad et al. (1955) is chosen to represent the concrete stress-strain relation in compression [5]. The experimental load-deflection data were obtained from the load-deflection diagrams of 87 beams under four-point bending test.

4. RESULTS AND DISCUSSION

The data of 9 beams from the set of 87 beams with available experimental load-deflection results and 20% of the data of remaining 78 beams are randomly selected for control and are not take in developing the optimal model. the genetic algorithm was used to minimize Square Root of the Sum of the Squares of difference between experimental and analytical results as objective function and to obtain the optimal values of the model parameters. The dimensionless curves of the model with the initial and optimal parameters are plotted in Fig. 1. The average value of the initial and the optimal function (f_{ct} / f_{cr}) in the range of 1 to100 of $\varepsilon_t / \varepsilon_{cr}$ is 0.25 and 0.054, respectively, indicating that the average value of the optimal function or tension stiffening is decreased by 78%.

The control data which is 20% of data of 78 beams and randomly selected, is used to check the accuracy of the of experimental/calculated deflection ratio of control data, which is zero if the analytical and experimental results are fully matched, is 1.0457 and 0.02668 for the obtained optimal parameters. The mean natural logarithm reduction. The mean experimental/ analytical deflection ratio of control data is 2.845 and 1.306 for the initial and optimal model, respectively, indicating that both models produce nonconservative results.

For control beams, the mean natural logarithm of experimental/calculated deflection ratio of control beams using the optimal model was significantly reduced by about 80%. To observe the effect of optimizing the tension stiffening model, experimental load – deflection curve and analytical load – deflection curves with the initial model and the optimal model along with the results of the deflection analytical relation presented in the ISIS Canada (2001) [6] and developed by Bischoff (2005) [7] for three cases of control beams (CB6-1[8], BC2[9], CFRP1[10]) are depicted in Fig. 2. For all three beams shown in Fig. 2, both analytical relations underestimate the moment rigidity of the member in the cracking region and are conservative, also their error is more than the error of the nonlinear analysis results, because a more accurate nonlinear relationship is considered for the stress-strain behavior of the materials in the nonlinear analysis.

5. CONCLUSION

Tension stiffening effect, which is due to stress transfer between concrete and reinforcing bars between cracks,

can be approach by the mean stress-strain relation of the concrete after cracking. This relation is used in section analysis by finite layer approach or truss analysis. In this research, by using section analysis by finite layer approach for a number of beams under four-point bending and comparing the analytical and experimental results in the service load range, the tension stiffening model proposed by Hsu and Zhu (2002) is modified by employing genetic algorithm optimization.

The optimal model predicts less tension stiffening effect than the original model for FRP bars, so that the average value of the optimal function is about %78 lower than the initial function in the range of cracking.

The mean natural logarithm of experimental/calculated deflection ratio of control data is 1.0457 and 0.02668 for the initial and optimal model, respectively, which shows a 74% reduction. The reduction in this parameter for control beams is also about 80%. It is noteworthy that the results of both models are non-conservative because their mean experimental to analytical deflection ratio is greater than one.

Comparison of the experimental and analytical load – deflection curve with the curves obtained from the two analytical relationships shows that both analytical relationships underestimate moment rigidity in after cracking region, for all three beams and these relationships are conservative but they have more error due to use less accurate stress-strain

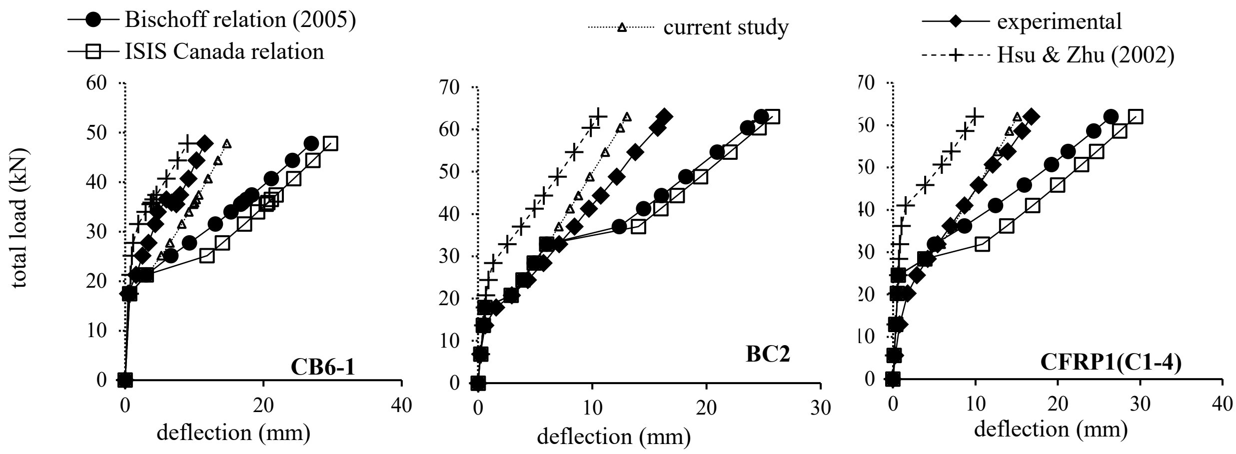

Fig. 2. comparison of Experimental load-deflection curve with curves obtained from analytical models and relations

behavior for materials than nonlinear analysis.

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HOW TO CITE THIS ARTICLE

A. Kamali, S.R. Mousavi, M.R. Ghasemi, Optimization of concrete tension stiffening model based on layered nonlinear analysis of FRP – RC beams, Amirkabir J. Civil Eng., 52(11) (2021) 683-686.

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