An Analytical Model For Analysis of Steel-Concrete Composite Beams Under Monotonic and Repeated Loads

Dr.Ikhlas S. Sheet[1], Dr.Bayar. J. Al-Sulafani[2]

ORCID No:https://orcid.org/0000-0001-7594-1815
[1] Northern technical university, Mosul,
ORCID No: https://orcid.org/0000-0002-1829-4583
[2]University of Mosul,

Keywords

Nonlinear analysis, Composite beams, Repeated loads, Slip, Numerical model

Abstract

This paper presents a numerical model for non-linear analyze steel-concrete composite beam subjected to monotonic and repeated loading with partial and full interaction. The model is constructed by a modified FORTRAN computer program. The nonlinear responsiveness for the composite beam is depending on dividing the element into fibers using a section layered method with the constituent materials hysteretic models. A derivation of the cyclic model for concrete, reinforcing bar and steel has been adopted. The behavior of the shear connectors under repeated load has also been derived. Since the slip between the components of composite beams is considered as a basic factor in the analysis, a slip model is adopted to estimate its amount. The numerical model is validated using experimental results. The results indicate that the presented numerical model can provide an effective tool for analyzing steel-concrete composite beam.

Research Article :
Submission Date : 07.04.2023
Accepted Date : 02.05.2023

1. INTRODUCTION

The structural behavior of steel-concrete composite beams that combine tensile of steel beam and compressive property of concrete slab relies on the interaction between them. So, the connection largely influences the behavior of beam, and its simulation is a key matter in analysis of these structures. In the last years, many research studied the mechanical behavior of composite beams, more attention was on the steel-slab interface (Jianguo, et al., 2004) effective slab width (Aref 2007) numerical studies (Ikbal et al., 2009), improved shear connectors rules (Lawson, M., et al, 2017). Modelling of composite beam with shear connection (Jianguo, et al., 2004) and (Marzi, S. and Enrico. S. 2001). This work introduces a numerical model to analysis composite beam under monotonic and repeated load by including bond slip interfaces. The results have been evaluated, using pervious experimental results.

2. MATERIAL PROPERTIES

2.1. Concrete

The cyclic behavior model under compression for concrete is shown in Figure 1 based on the monotonic stress-strain curve of (AL-Sulayfani, 1986). Cyclic model of concrete under compression in the current study is shown in Figure 2.

*Dr.Ikhlas S. Sheet; e-mail: ikhlas.sheet@ntu.edu.iq

2.2. Steel

The monotonic envelope for the stress-strain relationship of steel was idealism as elasto plastic behaviors and the shape of the curve is assumed to be optimal in both tensile and compressive areas as shown in Figure 3.İn this paper Menegotto-Pinto model was adopted (Menegotto and Pinto 1973) as shown in Figure 4.

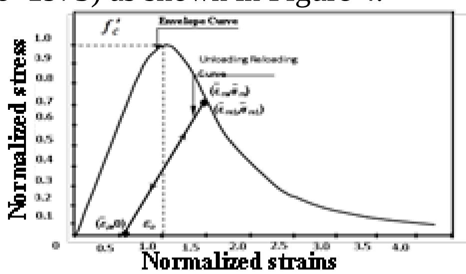


Figure 1. Cyclic model of concrete under compression

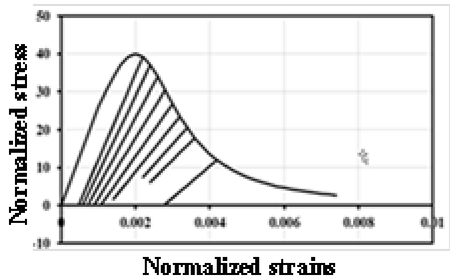


Figure 2. Cyclic model for compresion concrete (current study)

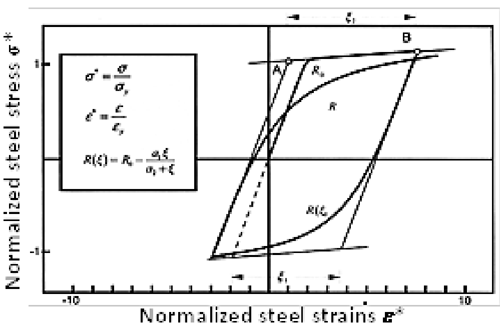


Figure 3. Menegotto and Pinto model

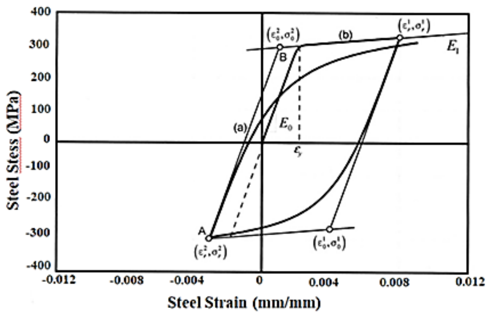


Figure 4. Cyclic model (current study)

2.3. Connectors

The flexural and slip behavior of composite beams are greatly affected by shear connectors feature ductility and stiffness. For shear connection consisting of headed studs the relationship defined by(Olgaard 1971) is used .Some curves representing the mechanical behavior of the headed studs are plotted in Figure 5. They were taking into account typical values of the two coefficients (α=0.558 and β=1 mm-1) in type A (α=0.989 and β=1.535 mm-1) in type B, or (α=0. 8 and β=0.7 mm-1) as in type C. In this study a derivation of model for stud connectors subjected to repeated loads has been presented in Figure 6.

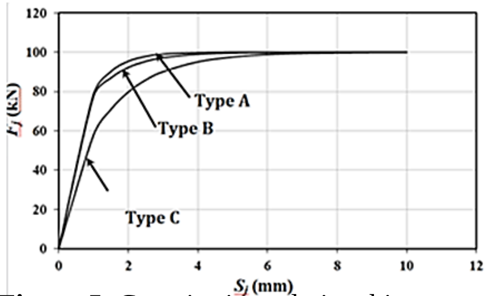


Figure 5. Constitutive relationship conne-ctors(Enrico S& Sherif, T 2004),

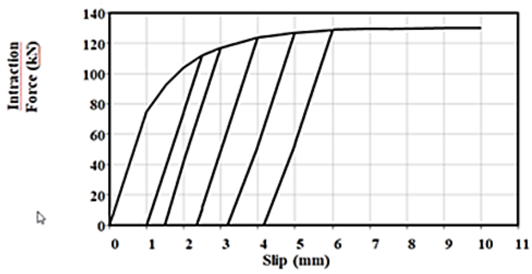


Figure 6. Cyclic model for connectors under repeated load (Current study).

3. PREDICTION OF INTERFACE SLIPS (JIANGUO & CAI, 2004)

The assumptions which were used in this study are : (i) The shear stress at the interface is commensurate to the slip,(ii) Same curvature for steel girder and concrete flange. (iii) For basically, section is symmetric about its vertical axis. For beam illustrated in Figure 7and from equilibrium ,the slip computed based on the Eqs.(1) and (2): Jianguo, and Cai (2004),

(1)

$$\varepsilon_{slip} = \frac{\alpha 1 \beta 1\, P\left(e^{-\alpha 1x} - e^{\alpha 1x - \alpha 1L} \ - e^{-\alpha 1x}\right)}{2\left(1 + e^{-\alpha 1L}\right)} \quad (1)$$

$$\Delta\phi = \frac{\varepsilon_{cs}}{h_c} = \frac{\varepsilon_{ss}}{h_s} = \frac{\varepsilon_s}{H} \quad (2)$$

4. NONLINEAR SECTIONAL ANALYSIS

The idea of the fiber section model is simple. The section is segmented into (n) fibers (equal area is not a necessity), concrete, structural steel or reinforcing steel can be assigned to a fiber.

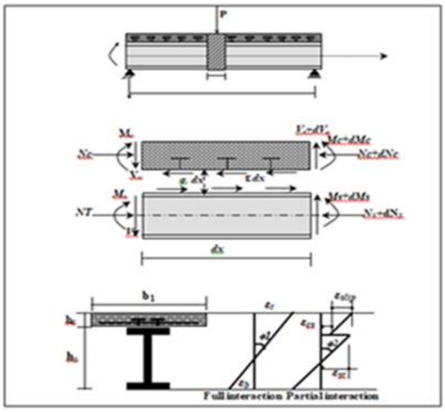


Figure 7. Calculated model for simply supported beam

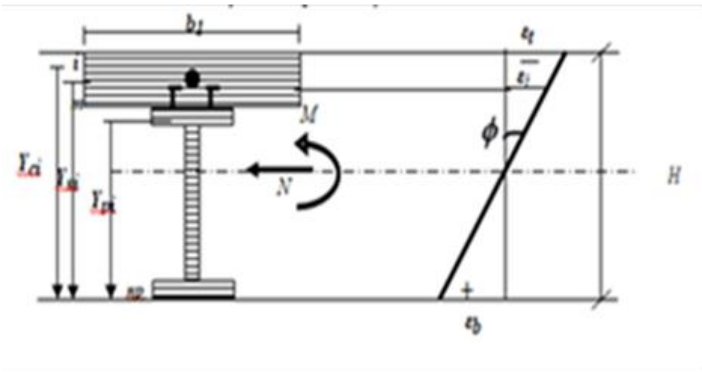


Figure 8. Section of simply supported beam

Assuming plane sections remain plane and from relevant constitutive models, fiber stresses are measured from strain fiber. To be an accurate analysis of the section, the internal stresses due to repeated impact loads must be calculated. Internal stresses require true distribution along the depth of section in order to achieve equilibrium and then it can be calculated the neutral axis and curvature, then modify the value of curvature after calculation of the value of slip between concrete and steel fragment. The steps of nonlinear analysis are summarized.

Step-1: The basis of analysis process is to get a balance between internal forces and moments with external forces and moments($N_{ext} = N_{int}$) and ($M_{ext} = M_{int}$). At the beginning must know external loads of axial force (N_{ext}) and moment (M_{ext}) affecting composite section, then divide the section into a number of layers to (m, n and n_p,) which represent the number of the concrete layers, elements of reinforced bar and number of steel section layers respectively as shown in" Figure 8.

Step-2: determine upper and lower strain layers of the section (ε_t) and (ε_b)

$$\varepsilon_t = \frac{\varepsilon_{t_{max}} + \varepsilon_{t_{min}}}{2} \qquad \varepsilon_b = \frac{\varepsilon_{b_{max}} + \varepsilon_{b_{min}}}{2} \quad (3)$$

Step-3: determine the strain at the center of each layer of concrete section (n) , reinforced bar (m) and steel section (n_p) by the following equations:

$$\varepsilon_{ci} = \varepsilon_t - \frac{\varepsilon_t - \varepsilon_b}{H}\left(H - Y_{ci}\right) \quad \varepsilon_{si} = \varepsilon_t - \frac{\varepsilon_t - \varepsilon_b}{H}\left(H - Y_{si}\right) \quad \varepsilon_{pi} = \varepsilon_t - \frac{\varepsilon_t - \varepsilon_b}{H}\left(H - Y_{pi}\right) \quad (4)$$

Step- 4: Calculate the stress in each layer of concrete from the theoretical models of the material constitutive relationships for concrete, reinforced bar and steel section respectively, which corresponds to the strains calculated from step 4.
Step- 5: Calculation internal responses of internal axial force (N_{int}) and internal moment (M_{int}) as follows:

$$N\,\text{int} = \sum_{i=1}^{m} f_{ci}.A_{ci} + \sum_{i=1}^{n} f_{si}.A_{si} + \sum_{i=1}^{np} f_{pi}.A_{pi} \tag{5}$$

$$M\,\text{int} = \sum_{i=1}^{m} f_{ci}.A_{ci}.(Y_{ci}) + \sum_{i=1}^{n} f_{si}.A_{si}.(Y_{si}) + \sum_{i=1}^{np} f_{pi}.A_{pi}.(Y_{pi}) \tag{6}$$

Step- 6: Comparing the computed internal force with the external force, if the difference between the two in what is permitted as in Eqution. (7) then going to step 7 or if not then must modify minimum or maximum strain in the upper layer(εt_{min}, εt_{max}).

$$\left(\left|\frac{N_{\text{int}} - N_{ext}}{N_{ext}}\right| \le 1\%\right), \left(\left|\frac{M_{\text{int}} - M_{ext}}{M_{ext}}\right| \le 1\%\right) \tag{7}$$

If the Nint < Next then εt min modify to take the current value of εt .If the N_{int} > Next then ε_t max modify to take current value of ε_t ,Then calculate the new value of ε_t by Eq. 3. Then going to the step or if not then must modify min or max strain in lower layer (εb_{min}, εb_{max}).

If Mint < Mext then εb min modify to take current value of εb ,If the M_{int} > M_{ext} then εb_{max} modify to take the current value of εb,Caculate the new value of εb from Eq. 3.

Step- 7: Comparing computed Mint with M_{ext} if the difference in what is permitted in Eq. 7.

Step 8: calculate the central strain ε_{cl} and the curvature ($Ø_1$)

$$\varepsilon_{cl} = \frac{\varepsilon_b + \varepsilon_t}{2} \qquad \phi_1 = \frac{\varepsilon_t - \varepsilon_b}{H} \qquad \phi_2 = \phi_1 + \Delta\phi \tag{8}$$

4.1. Flow Chart For Nonlinear Analysis of The Composite Section

The implementation of the model to enter numerical data on the number and description of cross sections of the engineering members of composite beam in the computer program, these include the number of data layers. The program calculates the strains and stresses at the center of each layer of concrete ,reinforced bar and steel section under the external loads to make a balance between them and responses of the Internal. The program calculates the value of the slip ,strain slip and strength of the connections at any distance from the length of the beam.

5. RESULTS AND DISCUSSION

5.1. Slip Effects Under Monotonic Load

A comparison with experimental beam tests by Abdel aziz,K. (1986) was involved in this study to assist validity of the numerical model in terms of mid-span deflection and slip of the connectors. Table 1. shows mechanical and geometrical characteristics of the cross section.A good agreement in terms of load–deflection was achieved between experimental and numerical technique as shown in Figure 9. Figure 10. shows slip distribution along left half of composite beam for two loaded levels and a decent agreement is observed.

5.2. Load-Deflection Curves Under Repeated Loads

Non-linear analysis conducted on composite beam. Table 2. demonstrates geometrical mechanical properties of cross section used in the analysis. Figure 11.displays the moment – deflection curve under repeated loads and Figure 12. shows load deflection curve. The increase of deflection is obvious in case of partial interaction compared with full interaction.

Table.1 The mechanical and geometrical properties of the cross section

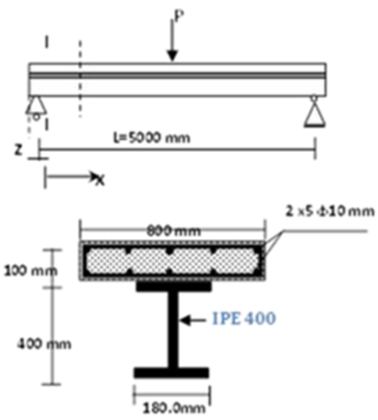
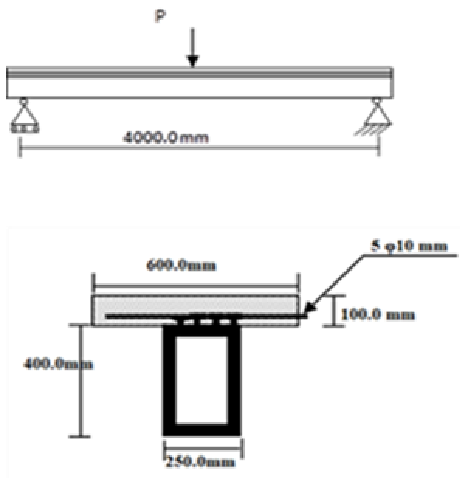
Properties of materials	Section dimension
Concrete: E_c=33163MPa f'_c=35 MPa **Reinforced bar:** E_s=200 GPa f_y=350MPa f_u=375 MPa **Steel** E_s=200GPa f_y=350 MPa f_u=375) **Shear connectors:** Dia..= 19 mm Length=80 mm Space between pair = 650mm E_s=200GPa f_y=370 MPa	

Table 2. The mechanical and geometrical

Properties of materials	Section dimension
Concrete: E_c=2400(MPa) f'_c=25 (MPa) **Reinforced bar:** E_s=200000(MPa) f_y=245 (MPa) **Steel:** E_s=200 (GPa) f_y=245 (MPa) f_u=361 (MPa) **Shear connectors:** Dia.= 19 mm Length=80 mm Pair Space = 600mm E_s=200 (GPa) f_y=370 (MPa)	

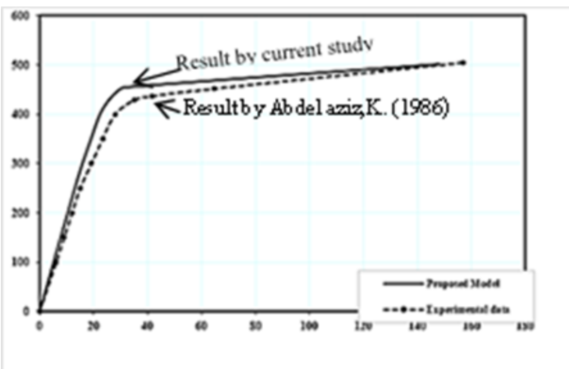


Figure 9. Load – Deflection curve for PI4

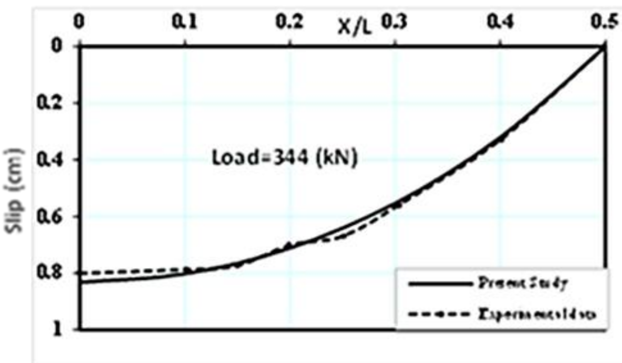
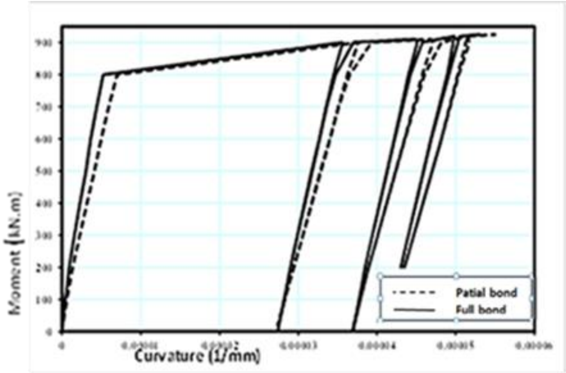
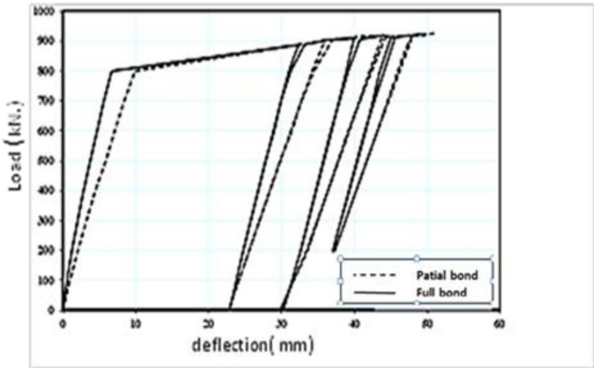


Figure 10. Slip distribution along PI4



Figuer 11. Moment–curvature curve (current study)



Figuer 12. Load–deflection curve (current study)

6. CONCLUSIONS

The following points can be summarized due to numerical study presented in this work:
A true replica of the materials stress-strain characteristics is the basic requirement for simulation of inelastic behavior up to the collapse of ductile structures. This computational technique allows the use of complex material models under repeated and cyclic loading and relates them with the structural behavior rather accurately. Since the stress distribution along the sections seems to be rather close to the real state. The method of layer section is proven to be efficient in a nonlinear analysis of concrete members.
The shear connectors that are used to connect elements together depend on slip that partially interacts to transfer of longitudinal shear. This results in the complexion of behavior of composite structures which is necessary to allow a slip in mathematical model. (Jianguo and . Cai 2004).

Conflict of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this paper.

Contribution of Authors

[Author 1's Dr.Ikhlas S. Sheet] Conceived and designed the study, collected and analyzed the data, and wrote the manuscript.
[Author 2's Dr.Bayar. J. Al-Sulafani]: research supervisor.

References

Abdel-Aziz, K.,(1986). Modelisation et `etude experimental de poutres mixtes acier-beton aconnexion partielle ou espacee, Ph.D. Thesis, Institute National des Sciences Appliquées des cholar. Google Scholar

AL-Sulayfani, B.J. (1986). Contribution Du Comportement Desossatures En Beton Arme Sous Sollicitations Cycliques Analyse Non-Linear (Docteur). De 1`University De Nantes, https://scholar.google.co.uk/citations?user=ygyhqisAAAAJ&hl=en.

Aref, A.(2007). Effective Slab Width Definition for Negative Moment Regions of Composite Bridges" Journal of Bridge EngineeringVol.12. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%2910840702%282007%2912%3A3%28339%29

Enrico S, Sherif, T ,(2004). Nonlinear analysis of steel-concrete Composite structures: state of the art. Journal of Structural Engineering, ASCE, Vol. 130. 24-34.doi: 10.1061/(ASCE)0733-9445(2004)130:2(159)

Eurocode 4 (1994): Design of composite steel and concrete structures — Part 1-1: General rules and rules for buildings ENV 1994-1-1, https://www.phd.eng.br/wp-content/uploads/2015/12/en.1994.1.1.2004.pdf

Fabbrocino ,G., Cosenzc,G.(1999), Nonlinear Analysis of Composite Beams under Positive Bending, Computers and Structures, Vol. 70, PP. 77-89.DOI:10.1016/S0045-79495(98)00173:4

Ikbal,N. Korkess,A. Yousifany, H. , & , Husain, H.(2009). Behavior of Composite Steel-Concrete Beam Subjected To Negative Bending. Engineering and technology journal, Vol 27, 53-71 https://www.iasj.net/iasj/article/28498.

Jianguo Nie; Jiansheng Fan; & C. S. Cai (2004): Stiffness and deflection of steel-concrete composite beams under negative bending. Journal of Structural Engineering, ASCE, Vol. 130, 1842-1851. https://ascelibrary.org/doi/10.1061.

Lawson, R. and Aggelopoulos, E. Obiala and F. HanusC. Odenbreit and S. NellingernU. Kuhlmann and F. Eggert D. Lam, X. Dai and T. Sheehan 2017. "Development of improved shear connection rules in composite beams" - Final Rep. https://constructalia.arcelormittal.com/files/R&D%20report%20DISSCO%20en--6c334a425cf171309240b225dc8c61ec.pdf.

Marzi ,S and Enrico. S,2001. Analysis of steel concrete composite frames with bond-slip, Journal of Structural Engineering ASCE Vo.127, 1243-1250. https://web.archive.org/web/20040920122531id_/http://civil.colorado.edu:80/~spacone/SalariSpacone-ASCE-ST-11-2001.pdf

Menegotto,M. ,Pinto,P.E.1973. Method of analysis for cyclically loaded reinforced concrete plane frame including changes in geometry and non elastic behavior of elements under combined normal force and bending", Proceedings of IABSE symposium, Lisbon. https://www.e-periodica.ch/cntmng?pid=bse-re-001:1973:13::9.

Ollgaard,J. Slutter,R. Fisher.J. (1971). Shear strength of stud connectors in lightweight and normal weight concrete. Journal of Structural Engineering ASCE Vol.8, 71-10. https://core.ac.uk/download/pdf/228628783.pdf.