Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 5, Issue 11, November -2018

The Effective Width of a Partially Composite Steel-Concrete Beam

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Abstract —*A composite section is made up of a concrete slab attached to a steel beam by means of shear connectors. Under positive bending moment, part of the slab will act as the flange of the composite beam resisting the longitudinal compression. In this paper a three-dimensional linear finite element analysis, using ANSYS program, is employed to evaluate and determine the actual effective slab width of a partially composite steel-concrete beam with variable degrees of partial interaction.*

Eight node isoparametric elements have been used to model the reinforced concrete slab, while the steel reinforcing bars are modeled as axial member (bar element) connecting opposite nodes between brick element with full bond assumption. The steel beam is modeled by four-node isoparametric shell elements, a spar bar element which has two end nodes with three translation degrees of freedom at each end has been used to model the shear connectors to resist uplift. The effect of dowel action of shear connector through the interface between top flange of the steel girder and concrete slab is modeled by combin element; the interface between two surfaces is modeled by contact element.

From analysis results, the stresses of concrete and steel are compared with stresses obtained from T-beam theory for variable degrees of partial interaction. From results obtained, it was found that, the partial interaction of composite beams is a minor effect on effective slab width.

Keywords- *composite beam, effective width, partial interaction, shear connector, shear lag*

I. INTRODUCTION

Composite construction consists of using two materials together in one structural unit and using each material to its best advantage. The number of combinations is almost endless; steel and concrete, timber and concrete, timber and steel, precast and cast-in-place concrete, etc… (Al-Sherrawi, 2000) [1].

Composite steel-concrete beams are used widely in modern bridges and buildings construction. a composite beam is formed when a steel component, such as an I-section beam, is attached to a concrete component, such as a floor slab or bridge deck, The fact that each material is used to take advantage of its best attributes makes composite steel-concrete construction very efficient and economical. However, the real attraction of composite construction is based on having an efficient connection of the steel to the concrete, and it is this connection that allows a transfer of forces and given composite member unique behavior [2]. Although the word composite may refer to all kinds of different materials connected together, in this study the term composite beam means steel beam attached to a reinforced concrete slab by means of mechanical connectors (shear connectors) as shown in Figure (1). The functions of these connectors are to transfer horizontal and normal forces between the two components, thus sustaining the composite action.

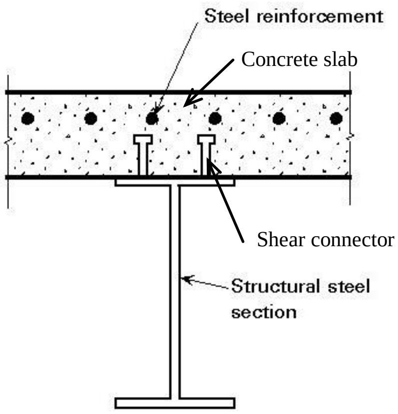

Figure (1) Typical composite steel-concrete beam

Greatest economic and structural benefit is generally realized when the concrete slab and the steel beam act under perfect composite action. Theoretically, this can only be realized if there are no relative movements at the interface of the slab and the upper flange of the steel beam. In practice, however, because of the deformability of the shear connectors, or when using fewer connectors than the number required for full interaction, some slip and vertical separation between the concrete slab and the steel beam would occur.

When the spacing between beams becomes large, it is evident that the simple beam theory does not strictly apply because the longitudinal stress in the flange will vary with distance from the beam web, the flange being more highly stressed over the web than in the extremities. This phenomenon is termed "shear lag".

Shear lag has long been of interest to researches. Adekola (1974a) [3] formulated and solved constitutive equations which relate partial interaction with shear lag by series solutions for deflections and in-plane stress in the slab to satisfy all the known boundary conditions. Adekola (1974b) [4] presented analysis for the interaction between non-prismatic beams and an orthotropic concrete plate, based upon the linearized theories of the bending and stretching of thin plates. Sun and Bursi (2005) [5] proposed displacement-based and two-filed mixed beam elements for the linear analysis of steel–concrete composite beams with shear lag and deformable shear connection.

Al-Sherrawi and Mohammed (2014) [6] carried out parametric studies to inspect the effect of some important parameters on the effective width of a composite beam under different load conditions. Haigen and Weichao (2015) [7] established a differential equation of longitudinal forces at transverse section flange and cantilever flange according to the strain compatibility and the force equilibrium conditions about a composite T-girder. In order to investigate dynamic characteristics of steel-concrete composite box beams, Wangbao et al. (2015) [8] established a longitudinal warping function of beam section considering self-balancing of axial forces. Kalibhat and Upadhyay (2017) [9] carried a parametric study by considering various design parameters, such as, the span length, the degree of shear connection, cross section geometry of the steel beam and the concrete slab. Al-Sherrawi and Mohammed (2018) [10] studied the shear lag phenomenon in composite steel-concrete beams under a concentrated load. Different parameters related to beams geometry and concrete slab material were considered in the study of Lasheen et al. (2018) [11] to evaluate the effective slab widths at service and ultimate loads.

II. EFFECTIVE WIDTH

The effective width of a flange is the width of a hypothetical flange that compresses uniformly across its width by the same amount as the loaded edge of the real flange under the same edge shear forces. Alternatively, the effective width can be thought of as the width of theoretical flange which carries a compression force with uniform stress of magnitude equal to the peak stress at the edge of the prototype wide flange when carrying the same total compression force [12], the longitudinal compressive stresses at the top of the slab have a non-uniform distribution, as shown in Figure (2). Simple bending theory will give the correct value of the maximum stress (at point C) if the true flange width s is replaced by an effective width, such that the area ABCDE equals the area FGCHI.

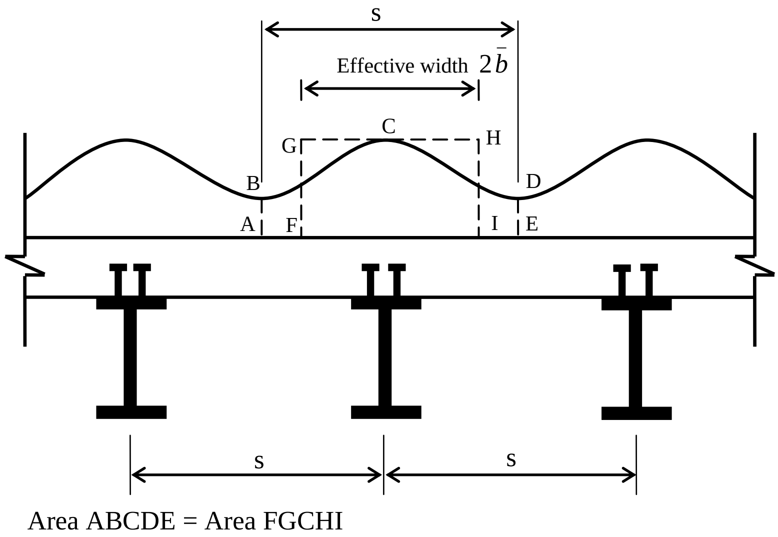

Figure (2) Lateral distribution of longitudinal normal stresses in slab (or wide flange)

Effective width may be defined in a variety of ways depending on which design parameter is deemed more significant. It is generally obtained by integrating the rigorously calculated longitudinal stress in the slab at top or mid surface, and dividing by the peak value of stress. In composite systems, the horizontal shear transmitted at the interface is regarded as more significant than flexing of the slab and therefore $\bar{b}$ is calculated here by considering top surface stress and is given by:

$$\bar{b} = \frac{\int_0^b \sigma_x \, dy}{(\sigma_x)_{\max.}} \qquad \text{………(1)}$$

where $\bar{b}$ is one-side effective slab width, b is one-side slab width, σ_x represent the normal stress in the longitudinal direction, and $(\sigma_x)_{max.}$ is the maximum normal stress between $0 \leqslant y \leqslant b$.

III. FINITE ELEMENT MODEL

ANSYS is a comprehensive general-purpose finite element computer program. It is capable of performing static and dynamic analysis. It is a very powerful and impressive engineering tool that may be used to solve a variety of problems.

A three-dimensional eight-node solid element (SOLID45) is used to model the concrete slab, while the steel reinforcement bar is modeled by a spare element (LINK8), in the modeling of the steel girder; a four-node shell element (SHELL63) is used. A spare element (LINK8) is used to model shear connector to resist uplift, while the dowel action of shear connector is modeled by combin element (COMBIN14), in the modeling of interface between two surfaces; a contact element (CONTAC52) is used as shown in Figure (3), and the geometry of these elements is shown Figure (4).

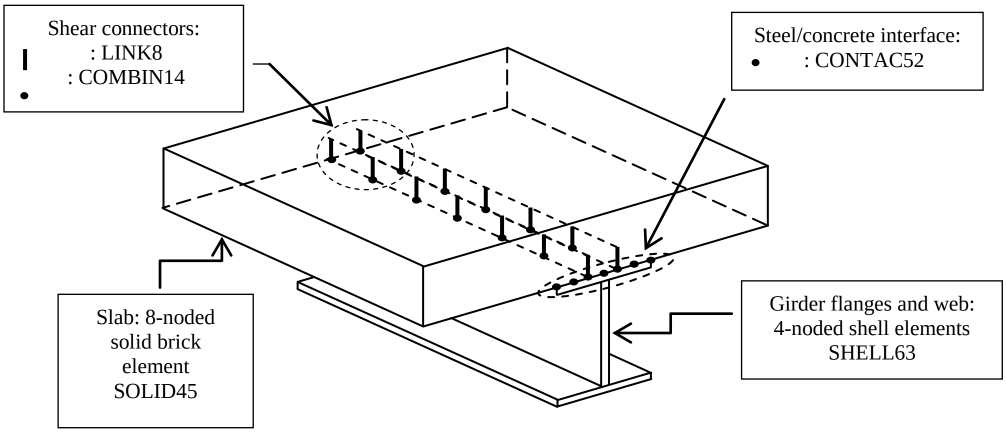

Figure (3) Schematic drawing of finite element model for composite beam

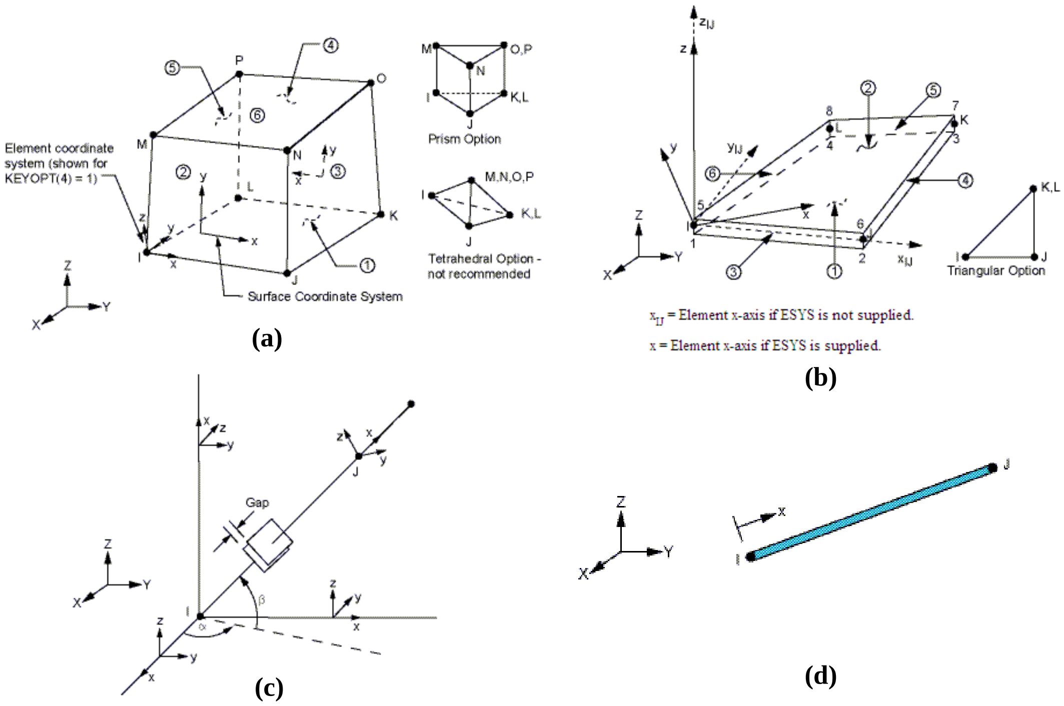

Figure (4) Elements geometry (a) SOLID45 (b) SHELL63 (c) CONTAC52 (d) LINK8 [13]

IV. FINITE ELEMENT VERIFICATIONS

The verification of the finite element modeling described above can be accomplished and comparing the results generated by the finite element analysis program (ANSYS V.10) to those obtained from the experimental test. In this paper, Yam and Chapman simply composite steel-concrete beam [14] is used to verify the accuracy and performance of the finite element models used in this study.

The simply supported composite beam, tested by Yam and Chapman, is one in a series of tested beams. The beam span was 5486 mm and subjected to a concentrated load at the mid-span. In the present study the chosen specimen is designated as beam (E 11). The dimensions and reinforcement details of this beam are shown in Figure (5).

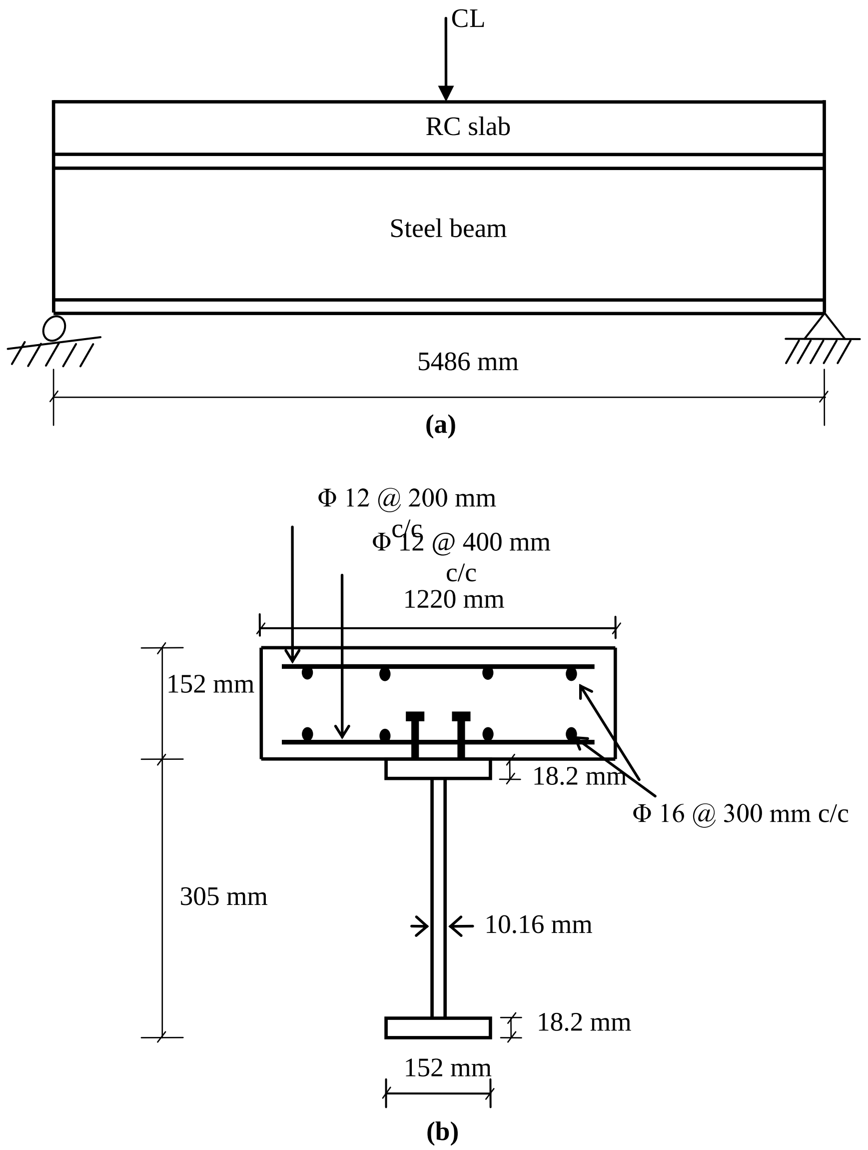

Figure (5) Yam and Chapman test beam (a) dimensions and loading arrangement of beam (E 11) (b) cross section

4.1. Finite element idealization and material properties

The three-dimensional finite element mesh for one half of the beam has been used by using (ANSYS 10) program, as shown in Figure (6). Concrete slab is idealized by using (1792) eight nodded brick elements (SOLID45), and steel beam is idealized by using (364) four nodded shell elements (SHELL63). Reinforcement is idealized by using (537) link elements (LINK8). The interface between the concrete slab and the steel beam (sticking and friction) is idealized by (145) two nodded contact elements (CONTAC52-point to point contact). Shear connectors are idealized by (100) link elements (LINK8) to resist uplift separation. The effect of dowel action of the shear connector through the interface between top flange of steel beam and concrete slab is modeled by (50) combine element (COMBIN14) to resist slip. The total number of nodes resulting from the above idealization is (2871) nodes, and the total number of element is (2988) elements.

Material properties of the Yam and Chapman composite beam are summarized in Table (1). In this analysis the symmetry has been used by using half span of the beam. The boundary condition of this beam is shown in Figure (6). The roller support is obtained by constrained displacement in y-axis, and at mid-span the symmetry condition is used, the symmetry condition is obtained by constrained displacement in x-axis for all nodes and rotations in z-axis for shell elements. The load applied (100 kN) at mid-span is distributed on rectangular area, as shown in Figure (6).

Table (1) Material properties used for Yam and Chapman steel-concrete composite beam

Material	Symbol	Definition	Value
Concrete	f'_c	Compressive (MPa)	50
	E_c	Young's modulus (MPa)	33234
	f_{ct}	Tensile strength (MPa)	4
	υ	Poisson's ratio	0.15
Reinforcement	f_y	Yield stress (MPa)	265 (ϕ 16)
			265 (ϕ 12)
	E_s	Young's modulus (MPa)	205000
	υ	Poisson's ratio	0.3
Steel beam	f_y	Yield stress (MPa)	265
	E_s	Young's modulus (MPa)	205000
Shear connector	L_s	Overall length (mm)	50
	φ	Diameter (mm)	12
	S_{stud}	Spacing (mm)	100
	E	Young's modulus (MPa)	205000
	k_s	Initial stiffness (kN/mm)	124

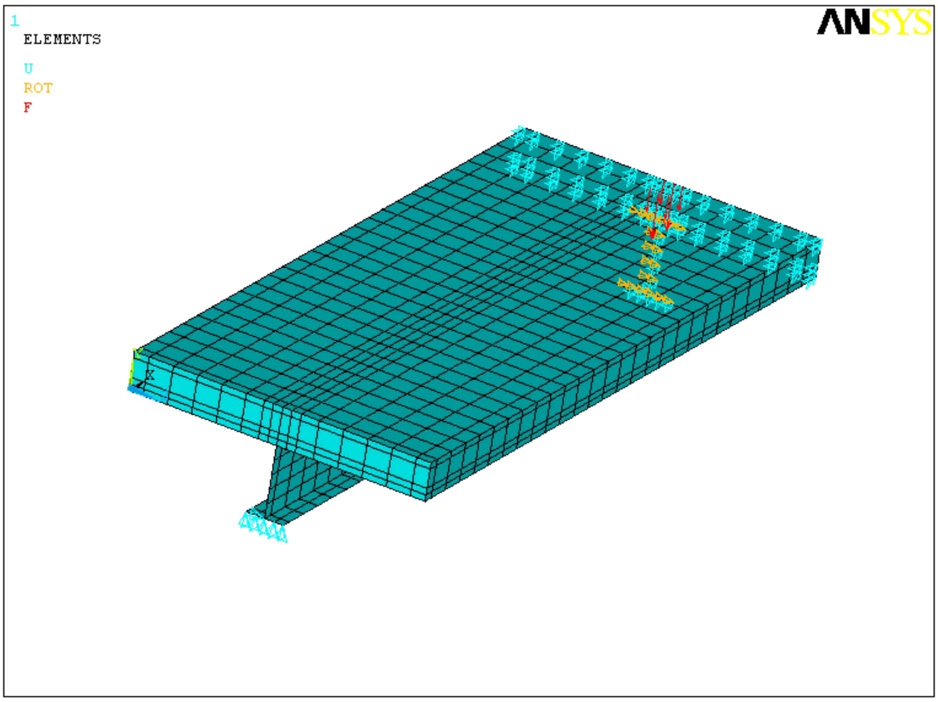

Figure (6) Three-dimensional finite element mesh for yam and chapman composite steel-concrete beam

4.2. Parametric study

The effect of partial interaction on Yam and Chapman composite beam has been investigated. To get full interaction, a large value for the stiffness of the shear connectors used by Yam and Chapman experimentally has been used by multiplying the stiffness value by 10^6. While for partial interaction, the number of shear connectors used by Yam and Chapman experimentally has been reduced as a percentage from the number of studs that has been used experimentally.

In this work, three types of loading are investigated:

a. Concentrated load (CL) (100 kN) (at mid-span).
b. Line load (LL) (18.228 kN/m) (on the longitudinal web axis).
c. Uniformly distributed load (UDL) (100 kN) (on the overall slab).

In this work, the numerator of the Eq. (1) was calculated by approximate method by using trapezoidal rule; these calculations have been done by a computer program written for this purpose.

The effect of partial interaction on the effective slab width with various degrees of interaction for three types of loading are shown in Figures (7-9), it can be seen from results obtained the effective width various from point to point along the span, for this beam the T- beam theory considers the effective slab width ($2\bar{b}$) is equal to the slab width (2b).

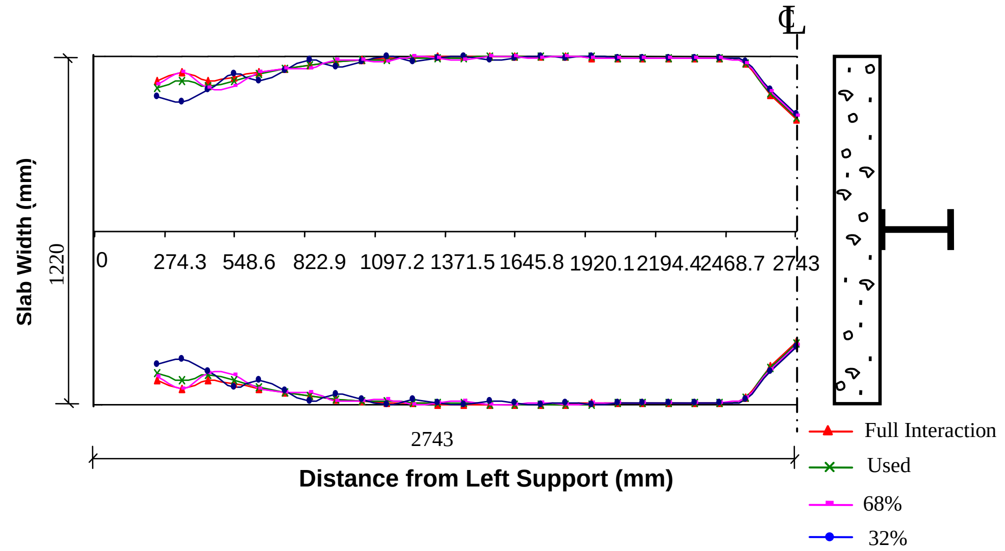

Figure (7) Effective width for CL (100 kN) for various degrees of interaction

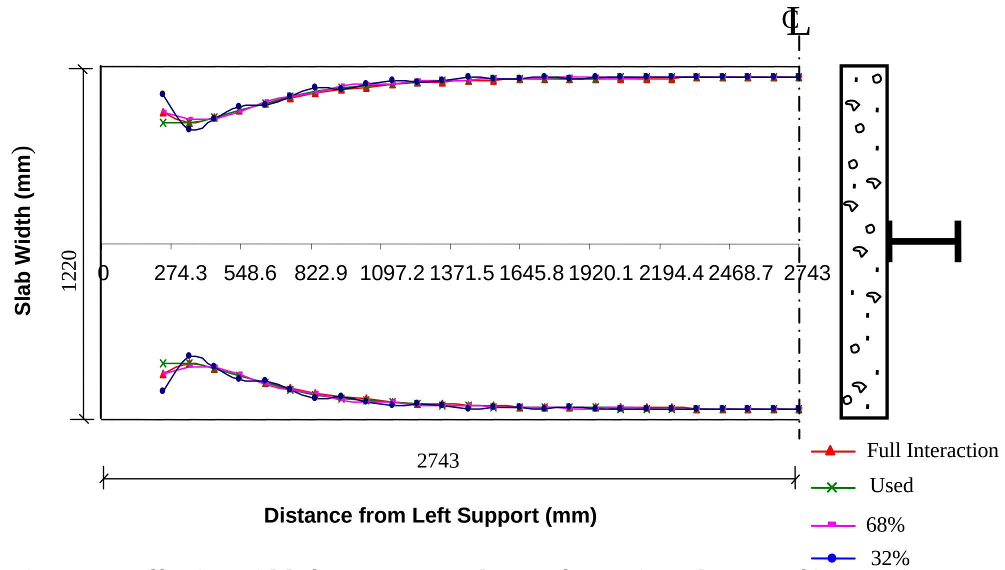

Figure (8) Effective width for LL (18.228 kN/m) for various degrees of interaction

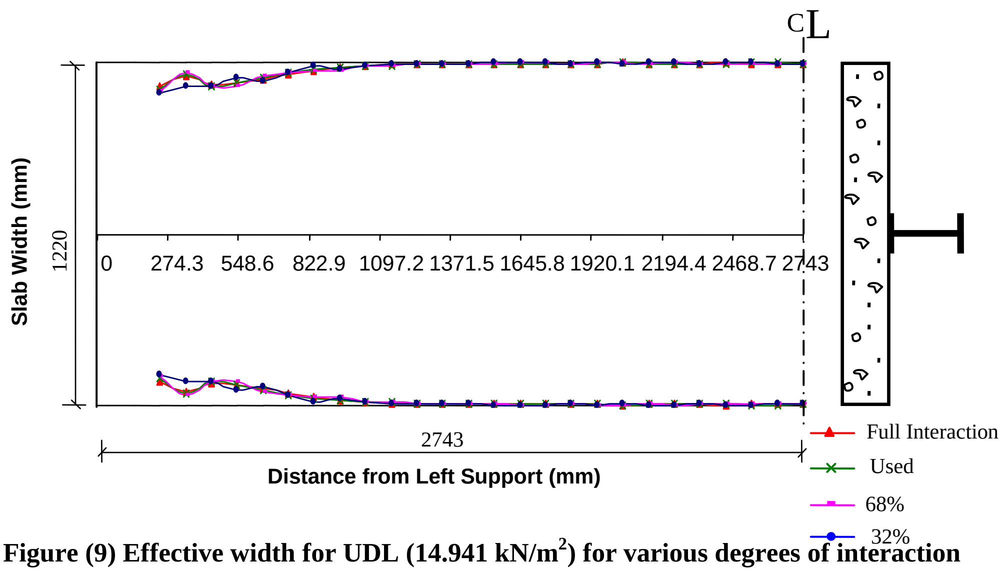

Figure (9) Effective width for UDL (14.941 kN/m^2) for various degrees of interaction

The effect of the degree of interaction on the effective slab width and maximum stress at mid-span for this beam for three types of loading has been listed in Tables (2 - 4) respectively. From the results obtained, it is seen that the effect of the degree of interaction on the effective width to be relatively minor, even for the wide range of degree of interaction considered. The maximum effect occurs under concentrated load situation, when the degree of interaction decreases from full to 32% the effective width increases only by 5%. Also, the effect of the degree of interaction on the maximum stress is relatively minor, even for the wide range of degree of interaction considered. The maximum effect occurs under uniform distributed load situation for the slab top surface stress, when the degree of interaction decreases from full to 32%, the maximum slab stress increases only by 7.5%, while for the maximum steel beam bottom flange stress the maximum effect occurs under concentrated load situation, the maximum steel beam stress increases only by 3%. The T-beam stresses have been calculated by simple bending theory.

Table (2) Effect of degree of interaction on the effective slab width ratio

Degree of interaction %	Number of Studs	Stiffness of Singe Stud kN/mm	Effective Width Ratio $\bar{b}/b$		
			Midspan		
			CL (100 kN)	*LL* (18.228 kN/m)	*UDL* (14.941 kN/m^2)
full	100	124*10^6	0.634	0.938	0.996
used	100	124	0.649	0.94	0.996
68	68	124	0.653	0.94	0.996
32	32	124	0.665	0.945	0.997

Table (3) Effect of degree of interaction on the maximum slab stress

Degree of Interaction %	Number of Studs	Stiffness of Singe Stud kN/mm	Maximum Slab Stress Ratio σ_c/σ_{ca}		
			MidSpan		
			CL (100 kN)	*LL* (18.228 kN/m)	*UDL* (14.941 kN/m^2)
Full	100	124*10^6	0.55	0.92	0.987
Used	100	124	0.538	0.897	0.96
68	68	124	0.533	0.885	0.948
32	32	124	0.522	0.857	0.913

Table (4) Effect of degree of interaction on the maximum steel beam stress

Degree of Interaction %	Number of Studs	Stiffness of Singe Stud kN/mm	Maximum Steel Beam Stress Ratio σ_c/σ_{ca}		
			MidSpan		
			CL (100 kN)	*LL* (18.228 kN/m)	*UDL* (14.941 kN/m^2)
Full	100	124*10^6	1.159	1.082	1.08
Used	100	124	1.143	1.075	1.073
68	68	124	1.138	1.072	1.07
32	32	124	1.124	1.062	1.06

Tables (5 and 6) are showing the comparison between the stresses obtained from T-beam theory and the analytical stresses.

Table (5) Ratio of maximum slab stress calculated from t-beam theory and finite element analysis at mid-span

CL		LL		UDL	
$\bar{b}/b$	**Maximum slab stress ratio, σ_c/σ_{ca}**	$\bar{b}/b$	**Maximum slab stress ratio, σc/σca**	$\bar{b}/b$	**Maximum slab stress ratio, σc/σca**
0.649	0.538	0.94	0.897	0.996	0.96

Table (6) Ratio of maximum steel beam stress calculated from t-beam theory and finite element analysis at mid-span

CL		LL		UDL	
$\bar{b}/b$	**Maximum slab stress ratio, σ_c/σ_{ca}**	$\bar{b}/b$	**Maximum slab stress ratio, σc/σca**	$\bar{b}/b$	**Maximum slab stress ratio, σc/σca**
0.649	1.143	0.94	1.075	0.996	1.073

V. CONCLUSIONS

The following conclusions can be drawn:

1. Effective slab width ($\bar{b}$) calculated from classical definition Eq. (1) depends on type of loading, the degree of interaction of composite steel-concrete beams has only a minor effect on the effective slab width.
2. Stresses in the steel beam calculated from the T-beam theory are conservative.

3. For a uniform distributed load on the slab, simple T-beam theory always predicted a safe maximum stress in the beam. However, the longitudinal stress distribution in the slab was markedly different from the uniform distribution assumed in T-beam theory.
4. The results for case line load are approximately the same results for case of uniform distributed load.

REFERENCES

[1] M. H. Al-Sherrawi, "Shear and Moment Behavior of Composite Concrete Beams," Ph.D. Thesis, Dept. of Civil Eng., Univ. of Baghdad, 2000.
[2] Oehlers, D. J., and Bradford, M. A. (1999) Elementary behavior of composite steel and concrete structural members, Linacre House, Jordan Hill, Oxford OX2 8DP, pp. 259.
[3] A. O. Adekola, (a) "The Dependence of Shear Lag on Partial Interaction in Composite Beams," International Journal of Solids Structures, Vol.10, pp. 389-400, 1974.
[4] A. O. Adekola, (b) "On Shear Lag Effects in Orthotropic Composite Beams," International Journal of Solids and Structures, Vol. 10, pp. 735-754, 1974.
[5] F. F. Sun and O. S. Bursi, "Displacement-Based and Two-Filed Mixed Variational Formulation for Composite Beams with Shear Lag," Journal of Engineering Mechanics, ASCE, Vol.131, No. 2, February, pp. 199-210, 2005.
[6] M. H. Al-Sherrawi, and S. N. Mohammed, "The Effective Width in Composite Steel Concrete Beams at Ultimate Loads," Journal of Engineering- Univ. of Baghdad, vol. 20, No. 8, pp. 1-17, Aug. 2014.
[7] C. Haigen and J. Weichao, "Analytic Solutions of Shear Lag on Steel-Concrete Composite T－girder under Simple Bending," The Open Civil Engineering Journal, 9, pp. 150-154, 2015.
[8] Z. Wangbao, L. Shu-jin, J. Lizhong and Q. Shiqiang, "Vibration Analysis of Steel-Concrete Composite Box Beams considering Shear Lag and Slip," Mathematical Problems in Engineering, Volume 2015, Article ID 601757.
[9] M. G. Kalibhat and A. Upadhyay, "Effect of Partial Shear Interaction in Steel Concrete Composite Girders," IOP Conf. Ser.: Mater. Sci. Eng. 245 022044, 2017.
[10] M. H. Al-Sherrawi, and S. N. Mohammed, "Shear Lag in Composite Steel Concrete Beams," 1st International Scientific Conference of Engineering Sciences - 3rd Scientific Conference of Engineering Science, ISCES 2018 – Proceedings 2018-January, pp. 169-174, 2018.
[11] M. Lasheen, A. Shaat and A. Khalil, "Numerical evaluation for the effective slab width of steel-concrete composite beams," Journal of Constructional Steel Research, 148, pp. 124–137, 2018.
[12] E. C. Hamply, "Bridge Deck Behavior," Chapman and Hall, London EC4P 4EE, 1976.
[13] ANSYS Manual, Version 10, 2005.
[14] L. C. P. Yam, and J. C. Chapman, "The Inelastic Behavior of Simply Supported Composite Beams of Steel and Concrete," Proceedings of the Institute of Civil Engineers, Vol. 41, , pp. 651-683, Dec. 1968.

