International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

The Dependence of Shear Lag on Loading in Composite Beams

Ashour R. Dawood[1], Mohannad H. Al-Sherrawi[1]
[1]Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq

Abstract**—***A composite beam includes a concrete slab and a steel beam, which are connected by shear connectors. Under positive bending moment, the longitudinal compressive stresses in the concrete slab have a non-uniform distribution along the cross section because of the shear lag effect. In this work a three-dimensional linearly elastic finite element analysis has been done to study the variation of shear lag due to loading type in a composite steel concrete beam. Three types of loading cases have been investigated in this study; concentrated load, line load and uniformly distributed load. From results obtained, it was found that the longitudinal stresses distribution in the concrete slab at the midspan of a simply supported composite beam was markedly different from the uniform distribution assumed in T- beam theory and shear lag clearly affected by loading type.*

Keywords**—***Composite beam, elastic analysis, loading, shear lag, stress.*

I. Introduction

A composite steel-concrete beam is 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. Fig. 1 shows different positions of the steel beam with respect to the concrete slab in a composite beam.

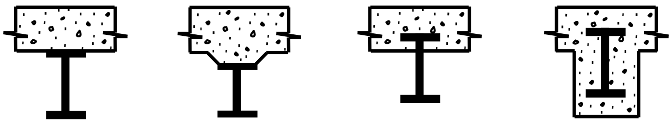

Fig. 1. Different positions of the steel beam.

The strength and stiffness of a composite beam depend on the degree of the composite action between the two components. The degree of a composite action in a composite member is related to the geometrical and mechanical properties of the shear connectors. The two commonly used terms that describe composite behavior are partial shear-connection and partial interaction, and these are related to the behavior of the connection between the steel and concrete components. Partial shear connection concerns equilibrium of the forces within a composite member, while partial interaction concerns compatibility of deformation of the steel concrete interface. Partial shear connection thus represents strength criterion, while partial interaction represents stiffness criterion.

The performance of any structure under load depends to a large degree on the stress-strain relationship of the material from which it is made. Composite beams are made of different materials (concrete, steel, shear connectors and reinforcing steel), which are brought together to work as a composite system.

From early load stages, as the shear causes slip to develop between the two parts, the composite beam behaves as a partially composite member (Al-Sherrawi, 2000) [1].

In ultimate strength analysis, such as the rigid plastic analysis, the behavior of the composite member is governed essentially by inelasticity and the nonlinear behavior of the steel and concrete components. However composite structures are usually loaded well below levels that would cause failure and the behavior of the steel, concrete and shear connection can be considered as linear. In limit state terminology, the behavior at these lower load levels is referred as service load behavior, or to the serviceability limit state (Oehlers and Bradford, 1999) [2].

A composite steel concrete beam is commonly used in construction, due to taking advantage of the mechanical characteristic of steel and concrete, namely the use of concrete compressive and steel tensile capacity. It is well known that the uneven deformation of the wider top flange (concrete) can produce an uneven distribution of the longitudinal stresses under symmetrical bending. The shear lag effect can result in the obvious increase of longitudinal stress near the edge of the flange and cause stress concentration. Due to shear lag effects, it can cause stress concentration in structure, structural damage even in early loading stages (Haigen and Weichao, 2015) [3].

II. Shear Lag

Since the beginning of the twentieth century, shear lag has of interest to researches. Earlier experimental and theoretical works were performed to evaluate the stresses distribution in flanged composite beams by Schule (1909) [4], Bortsch (1921) [5], Karman (1923) [6] and Metzer (1929) [7].

The effect of shear lag causes the longitudinal stress at flange/web connection to be higher than the mean stress across the flange. Therefore, the effect of shear lag has to be catered for in the analysis and design of beams, especially for those with wide flanges (Al-Sherrawi and Edaan, 2018) [8].

Adekola (1974) [9] formulated and solved constitutive equations, which relate partial interaction with shear lag by series of solutions for deflection and in-plane stresses in the concrete slab to satisfy all the known boundary conditions. Sun and Bursi (2005) [10] proposed displacement-based and two-filed mixed beam elements for the linear analysis of a steel concrete composite beam with shear lag and deformable shear connection.

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Al-Sherrawi and Mohammed (2014) [11] perform a parametric study to examine the effect of some significant parameters on the effective width of a composite beam under different load conditions. Haigen and Weichao (2015) [3] decided the shear lag coefficient by calculating the ratio between stress calculated by force equilibrium conditions about a composite T-girder, which gotten through established a differential equation of longitudinal forces at transverse section flange and cantilever flange according to the strain compatibility and the stress decided by elementary beam theory. Wangbao et al. (2015) [12] founded a longitudinal warping function of a beam section by considering self-balancing of axial forces to study dynamic characteristics of steel concrete composite box beams. Kalibhat and Upadhyay (2017) [13] carried out 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. Taig and Ranzi (2017) [14] presented a generalised beam theory formulation to study the partial interaction behaviour of two-layered prismatic steel–concrete composite beams. Al-Sherrawi and Mohammed (2018) [15] investigated the shear lag phenomenon in a composite steel concrete beam under a concentrated load. Lasheen et al. (2018) [16] considered different parameters related to beams geometry and concrete slab material to evaluate the effective slab widths at service and ultimate loads. Dawood and Al-Sherrawi (2018) [17] concluded that the degree of interaction of a composite steel-concrete beam has only a minor effect on the effective slab width.

III. FINITE ELEMENT VERIFICATION

To verify the finite element modeling that adopted in this study, a comparison has been made between the results generated by the finite element analysis program (ANSYS V.10) to those obtained from the experimental test. In this study, one of Yam and Chapman composite steel concrete beams has been used to verify the accuracy and performance of the finite element model used in this study. The span of the beam was 5486 mm and subjected to a concentrated load at its midspan. The dimensions and reinforcement details of this beam are shown in Fig. 2.

Fig. 3 presents the three-dimensional finite element mesh for one half of the beam. Three-dimensional eight-node solid elements (SOLID45) have been used to model the concrete slab, while the steel reinforcement bars have been modeled by spare elements (LINK8). Four-node shell elements (SHELL63) have been used in the modeling of the steel girder. Spare elements (LINK8) have been used to model shear connectors to resist uplift, while the dowel action of the shear connectors have been modeled by combine elements (COMBIN14). In the modeling of interface between two the concrete and steel surfaces contact elements (CONTAC52) have been used. The material properties of the beam are listed in Table I.

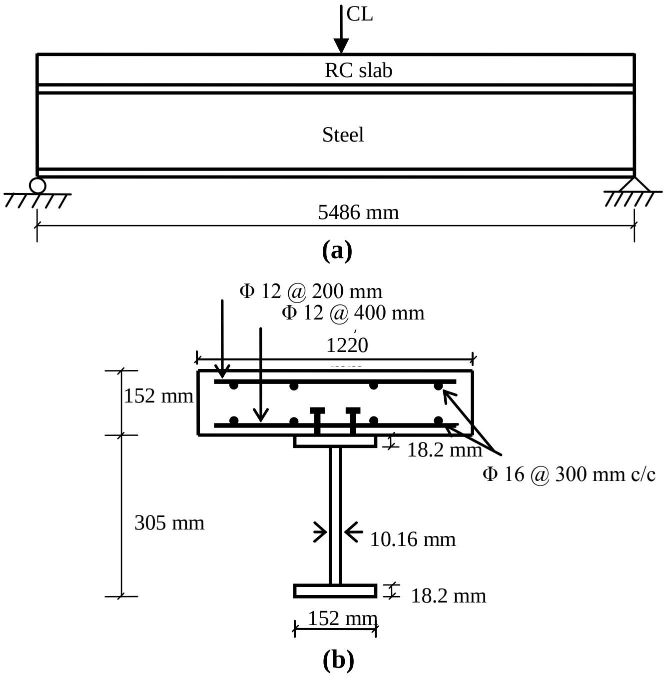

Fig. 2. Yam and Chapman tested beam (a) dimensions and loading arrangement of beam (b) cross section [18].

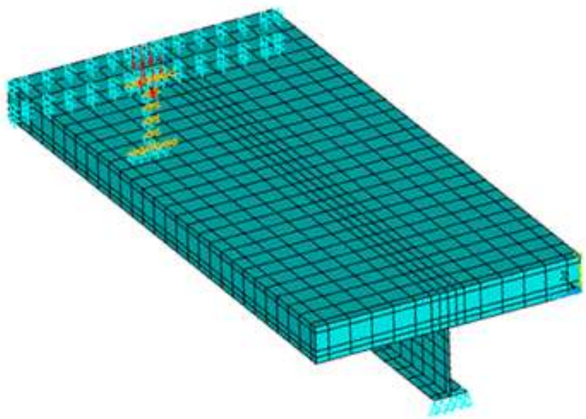

Fig. 3. Finite element idealization for Yam and Chapman composite steel concrete beam.

TABLE I. Material properties used.

Material	Definition	Value
Concrete	Compressive (MPa)	50
	Young's modulus (MPa)	33234
	Tensile strength (MPa)	4
	Poisson's ratio	0.15
Reinforcement	Yield stress (MPa)	265 (ϕ 16)
		265 (ϕ 12)
	Young's modulus (MPa)	205000
	Poisson's ratio	0.3
Steel beam	Yield stress (MPa)	265
	Young's modulus (MPa)	205000
Shear connector	Overall length (mm)	50
	Diameter (mm)	12
	Spacing (mm)	100
	Young's modulus (MPa)	205000
	Initial stiffness (kN/mm)	124

The results obtained using the finite element analysis carried out for the beam are presented and compared with the experimental data as shown in Table II. The experimental and analytical load-deflection curves are shown in Fig. 4.

TABLE II. Comparison between the analytical and experimental results.

Load (kN)	Deflection (mm)		Error (%)
	Analytical	Experimental	
50	1.9393	1.9242	0.78
100	3.8787	3.8484	0.78
150	5.8181	5.8964	1.32
200	7.7575	8.1642	4.98

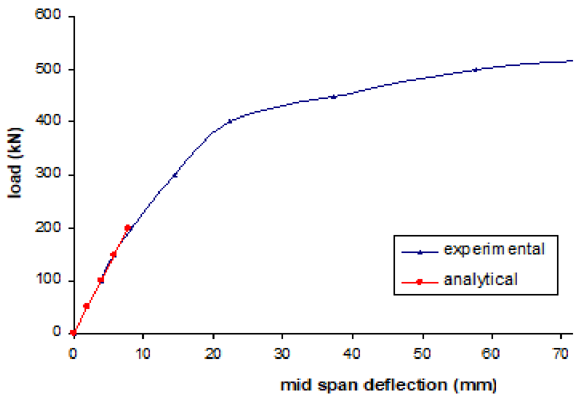

Fig. 4. Yam and Chapman composite steel concrete beam experimental and analytical load-deflection curve.

IV. Parametric Study

In this research, a total static load equals 100 kN has been adopted and three types of loading cases have been inspected:

a. A concentrated load (CL) (100 kN) (at midpoint of concrete slab top surface).
b. A line load (LL) (18.228 kN/m) (on the centerline of concrete slab top surface).
c. A uniform distributed load (UDL) (100 kN) (on the overall concrete slab top surface).

The distribution of the longitudinal stresses in the concrete slab has different shapes along the slab width according to type of loading as shown in the Figs 5-7. The distribution of the effective slab widths for the beam with respect to the three types of loading is shown in Fig. 8.

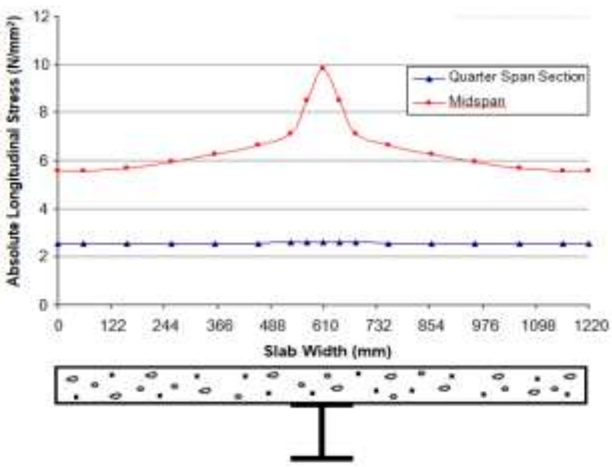

Fig. 5. Slab top surface stress distribution for Yam and Chapman beam for CL (100 kN).

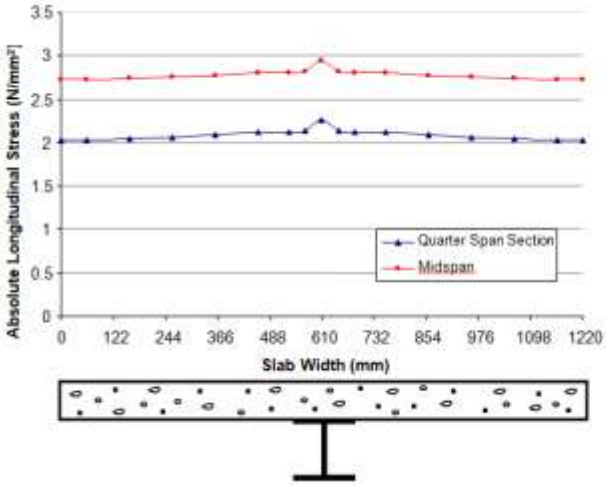

Fig. 6. Slab top surface stress distribution for Yam and Chapman beam for LL (18.228 kN/m).

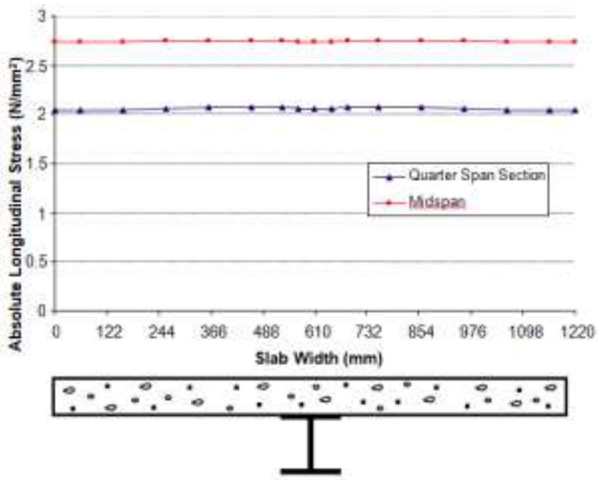

Fig. 7. Slab top surface stress distribution for Yam and Chapman beam for UDL (14.941 kN/m^2).

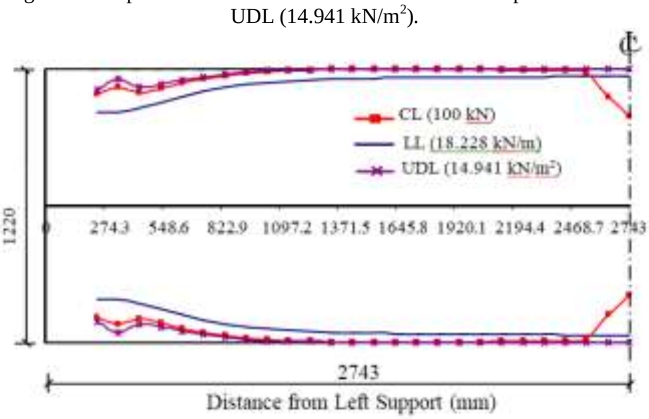

Fig. 8. Effective width for various loads for Yam and Chapman beam.

It can be seen from results obtained that the effective width various from point to point along the span of the composite beam. The Effect of the degree of interaction on the longitudinal compressive stress distribution at midspan for the beam for three types of loading is shown in Fig. 9.

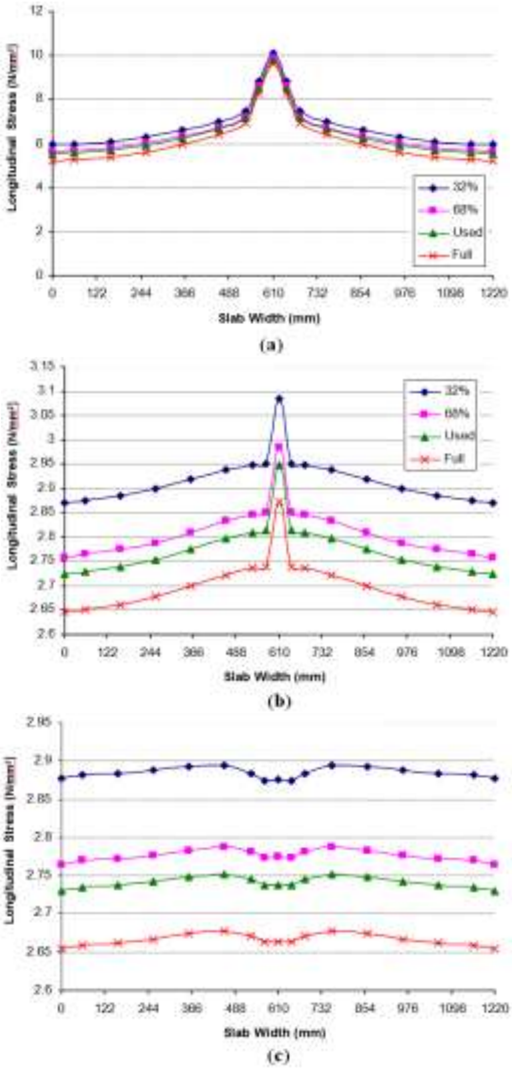

Fig. 9. Effect of degree of interaction on the stress distribution at midspan for Yam and Chapman beam (a) CL (b) LL (c) UDL.

V. CONCLUSION

1. The longitudinal stresses distribution in the concrete slab was markedly different from the uniform distribution assumed in T- beam theory.
2. The longitudinal stresses results for the case of line load are approximately the same results for the case of uniform distributed load.
3. Shear lag clearly affected by loading type.

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