BEHAVIOR OF MULTI-LAYER COMPOSITE BEAMS WITH PARTIAL INTERACTION "PART I "

Dr. Riyadh I. M. Al-Amery
Assistant Prof.
Dep. of Building& Construction
University of Technology

Dr. Zeyad M. Ali
lecturer
Dep. of Building& Construction
niversity of Technology

Dr. Khalel I. Aziz
lecturer
Dep. of Civil Engineering
University of Anbar

الخلاصة:

استخدمت المنشات المركبة بصورة واسعة في الهندسة الإنشائية خلال الخمسة والثلاثين سنة الماضية وطروت لأغلب الأجزاء الإنشائية الشائعة الاستخدام بسبب الفوائد المترتبة على هذا النوع من الإنشاءات . في هذه الدراسة جرت محاولة لتقديم طريقة تعتمد على نظرية المرونة لتحليل العتبات المركبة متعددة الطبقات تأخذ بنظر الاعتبار العلاقات الخطية وغير الخطية للمواد الإنشائية المستخدمة ورباطان القص . التحليل اعتمد بصورة رئيسية على التحليل المقترح من قبل روبرت . التحليل يقود إلى مجموعة من المعادلات التفاضلية (ثمان معادلات) من الدرجة الرابعة والثالثة .تم فحص ثلاثة نماذج من فحص القص لرباطان القص المستخدمة وأيضا" تم صب وفحص سلسة من العتبات المركبة المتكونة من ثلاثة طبقات مختلفة المواد والأبعاد . نتائج الفحوصات تمت مقارنتها بنتائج بعض الباحثين حيث تبين وجود تقارب جيد بين التحليل الإنشائي والفحص العملي ونتائج باحثين آخرين.

ABSTRACT:

In this study an attempt is made to develop a method of analysis dealing with a multi-layer composite beam, for linear material and shear connector behavior in which the slip (horizontal displacement) and uplift force (vertical displacement) are taken into consideration. The analysis is based on a approach presented by Roberts[1], which takes into consideration horizontal and vertical displacement in interfaces. The analysis led to a set of eight differential equations contains derivatives of the fourth and third order. A program based on the present analysis is built. Series of three push-out tests were carried out to investigate the capacity of shear stiffness for connectors. From these tests, load-slip curves were obtained. Also, series of multi-layer composite simply supported beams were tested. Each one consists of three layers in different material properties and dimensions. A comparison between the experimental values and numerical analysis is carried out. Close agreement is obtained with experimental values for different materials, layers thickness and shear stiffness.

NOTATION

a, b, and c= Subscript denotes different layers.

A_a, A_b and A_c = Cross-sectional area of different layers.

A = Effective width of concrete slab.

d_1 and d_2 =Distance between the centroids of successive layers.

E_1 = Modulus of elasticity of concrete.

E_2 = Modulus of elasticity of steel.

E_a, E_b and E_c =Modulus of elasticity of different layers .

F_a, F_b and F_c =The axial forces in different layers.

h_a, h_b and h_c = Thickness of different layers.

I_a, I_b and I_c =Second moment of area for the layer a.

I_1 and I_2 = Moment of inertia of concrete slab and steel about its own centroid.

k_{s1} and k_{s2} =Shear stiffness of the joint per unit length between successive layers.

k_{n1} and k_{n2} =Normal stiffness of the joint per unit length between successive layers.

L = span length.

M= External applied moment.

M_a, M_b and M_c =Moment for layer a.

P_1 and P_2 =Normal force per unit length at the upper and lower interface.

ρ_i =Live load.

ρ =Live load and dead load.

ρ_a, ρ_b and ρ_c = Distributed self-weight of layer a.

R_r, R_l =Reaction at the right and the left supports.

U_{ab} and U_{bc} = Slip between upper and lower layers.

u_a, u_b and u_c =Displacements of the different layers in the x -direction.

W= Point load.

w_a, w_b and w_c =Displacements of the layer a, b and c in the z -direction.

w_{ba}, w_{cb} =Separation at the interface between the upper and lower layers.

x.= Subscript denote differentiation.

z_{ai}, z_{ai} and z_{ai} =Z-coordinate of interface relative to local x-z axes in layers a, b and c.

ε_f =Free strain due to shrinkage, temperature etc.

ε_r = Strain induced during the construction sequence.

$\bar{\varepsilon}$ =Integration of strain function over cross section area of the material.

ε_a, ε_b and ε_c =Strain in layers a , b and c.

σ_a, σ_b and σ_c =Stress in layers a, b and c.

Δx =Spacing between nodes.

1.INTRODUCTION

Composite construction has been widely used for building construction over the past 50 years, developed initially for most structural elements due to the advantages provided by such types of elements. A perfect connection between the components of composite elements (mostly steel, concrete and timber) exists only theoretically. Experimental investigation has shown that significant slip occurs at the interface between these components, even when a large number of connectors are proved. Some types of connectors give a very rigid connection, others are more deformable in which a certain slip is inevitable. This problem is more complicated when fewer connectors than the number required for full interaction are used. The modification in the behavior of a composite beam by the presence of slip was illustrated by analysis conducted by many researchers. These analyses led to differential equations (number of these equations depending on the degree of freedom) that are to be solved fresh for each type of loading and the variation in dimensions or properties of beams. Multi-layer composite beam (also called laminated beam structures) are very important structures and relatively new which are used not in civil engineering only but in many industries such as aircraft and marine engineering. The first interaction theory that takes account of slip effects was initially formulated by Newmark [2], based on elastic analysis of composite beams assuming linear material and shear connector behavior. When the basic equilibrium and compatibility equations are reduced to a single, second order differential equation in terms of the axial force, equation (1) is obtained.

$$F_{xx} - \alpha_2^2.F = -\alpha_2^2.\beta_2.M \qquad ..(1)$$

where,

$$\alpha_2^2 = \frac{K}{S}\left[\frac{1}{A_c.E_c} + \frac{1}{A_s.E_s} + \frac{d_c^2}{E_c I_c + E_s.I_s}\right], \ \sum EI = E_c.I_c + E_s.I_s \ , \ \overline{EI} = \sum E.I + \overline{EA}.d_c^2$$

$$\frac{1}{\overline{EA}} = \frac{1}{E_c.A_c} + \frac{1}{E_s.A_s} \ , \ \beta_2 = \frac{\overline{EA}}{\overline{EI}}.d_c$$

K=shear connector

S=spacing between shear connectors.

The solutions of this basic differential equations is then substituted back into the equilibrium and compatibility equations, which can then be solved to give the displacements and strains throughout the beam and the slip at the interface.

Adekola [3] formulated equation (2) and (3) based on interaction theory, which takes account of slip, uplift and friction effect. Each component of a composite beam was assumed to behave separately in accordance with simple bending theory. In addition it was assumed that the rate of change of the axial force is directly proportional to slip, and uplift force is directly proportional to differential deflection. The equilibrium and compatibility relations lead to two differential equations of fourth order connecting the uplift tension arising from differential deflections of the two components of the composite beam with the axial force within each of the components. The equations contain derivatives of fourth order in uplift forces and second order in axial forces, and they were solved by a finite difference method, in which they were rearranged such that unknowns exist at each node point of a simply supported composite beam. Obtaining the complete solution for the axial forces and uplift forces, deflections can then be determined ,as follows;

$$T_{xxxx} + K_n\left[\frac{1}{E_s.I_s} + \frac{1}{E_c.I_c}\right].T + \frac{K_{n.}.\rho}{E_c.i_c} - K_n\left[\frac{Z_{si}}{E_s.I_s} + \frac{Z_{ci}}{E_c.I_c}\right].F_{xx} = 0 \qquad ..(2)$$

$$F_{xx} - K_s\left[\frac{1}{E_s.A_s} + \frac{1}{E_c.A_c} + \frac{d_1^2}{(E_cI_c + E_sI_s)}\right].F + \frac{K_{s.}}{K_n}\left[\frac{E_cI_cZ_{si} - E_sI_sZ_{ci}}{E_s.I_s + E_c.I_c}\right].T_{xx} = \frac{-K_s.d_c}{E_c.I_c + E_s.I_s}.M \qquad ..(3)$$

Using the same element presented by Newmark, Johnson [4] in 1975 proposed a partial interaction theory for simply supported beams, in which the analysis was based on elastic theory. The composite beam was assumed to be in linear elastic materials. The discrete connection was assumed to be smeared along the beam, so that the connector strength and stiffness can be quoted per unit length of beam. In addition, the connector behavior was assumed linearly elastic. The effects of uplift were neglected, i.e. no gap between the two components of the composite beam occurs and the same curvatures are used for them. Equations deduced from equilibrium, elasticity and compatibility were so arranged that a second order differential equation relating the slip at the interface to the distance along the beam were obtained, equation (4). The solution of the equation gives the slip distribution along the beam, back substitution into the equilibrium and compatibility equations get the curvature distribution deflections and stresses along the beam. Both of the two approaches analyze two layers of composite beam with partial interaction and gives single, second order explicit differential equation. This equation must be solved for each type of loading to have the complete solution.

$$U_{cs,xx} - \alpha_1^2.U_{cs} = -\alpha_1^2.\beta_1.N \qquad ..(4)$$

where,

$\beta_1 = \frac{A_1.S.d_c}{K}$, $\alpha_1^2 = \frac{K}{S.E_s.I_1.A_1}$, $I_1 = \frac{I_c}{m} + I_s$, $\frac{1}{A_o} = \frac{m}{A_c} + \frac{1}{A_s}$ and $A_1 = d_1^2 + \frac{I_1}{A_o}$

Roberts [1] presented an approach for the analysis of composite beam with partial interaction, in which the basic equilibrium and compatibility equations were formulated in terms of four independent variables, i.e. the axial displacements of the concrete and steel and the deflections of the two layers. Linear elastic materials and shear connector behavior were assumed with the concrete remaining uncracked, and both the slip and separation at the interface were incorporated. The analysis resulted in four differential equations, which contain derivatives of third order in axial displacements and fourth order in deflections. Numerical solutions of the basic equations were obtained by expressing them in finite difference form and the complete system of the equations, i.e. four per node, was solved for the unknown displacements and deflections. An application of the theory was made in which the behavior of a simply supported composite beam under service loading was studied. The normal stiffness of the shear connection per unit length was assumed infinite, i.e. no separation occurs and equal curvatures of the interaction components exist. The shear stiffness of the shear connections per unit length were varied such that uniform, triangular and discontinuous distribution of shear connectors were obtained.The basic equilibrium and compatibility equations were formulated in terms of four independent variables, i.e. the axial displacements and deflections of the layers, equations from (5) to (8). Linear elastic materials and shear connector behavior was assumed with the concrete remaining uncracked, and both the slip and separation at the interface were incorporated. The analysis resulted in four differential equations, which contain derivatives of third order in axial displacements and fourth order in deflections.

$$M_{c,xx} + M_{s,x} - F_{s,xx}.d_1 = \rho \quad ..(5)$$

$$F_{c,x} + F_{s,x} = 0 \quad ..(6)$$

$$F_{c,x} - k_s\left[\left(U_c - Z_i.W_{c,x}\right) - \left(U_s - Z_{si}.W_{s,x}\right)\right] = 0 \quad ..(7)$$

$$M_{c,xx} + F_{c,xx}.Z_{ci} - K_n(W_s - W_c) = \rho_i + \rho_c \quad ..(8)$$

2.Theory[1]

2.1 Assumptions

The basic assumptions of conventional beam theory were used where plane sections are assumed to remain plane. Also, the connection was assumed to have negligible thickness and possesses finite normal and tangential stiffness.

2.2 Equilibrium .

An element of a composite of three layers, length (δx), shown in Figure (1), is subjected to moments, (M), shear forces, (V), and axial forces, (F), subscripts a, b, and c denote, three layers from upper to lower layer, and the local x-z axes pass through the centroids of the materials. The beam subjected to uniform distributed load The equilibrium requirements led to the following equations:

$$M_{a,xx} + M_{b,xx} + M_{c,xx} - F_{b,xx}.d_1 - F_{c,xx}.(d_1 + d_2) = \rho \quad ..(9)$$

$$M_{a,x} + M_{b,x} + M_{c,x} = V_a + V_b + V_c - F_{a,x}.d_1 + F_{c,x}.d_2 \quad ..(10)$$

$$F_{a,x} + F_{b,x} + F_{c,x} = 0 \quad ..(11)$$

2.3 Compatibility

Assuming plane sections within each material remain plane, The compatibility requirements lead to the following equations:

$$F_{a,x} - k_{s1}[(u_a - z_{ai}.w_{a,x}) - (u_b - z_{bi}.w_{b,x})] = 0 \quad ..(12)$$

$$F_{a,x} + F_{b,x} - k_{s2}[(u_b - z_{bi}.w_{b,x}) - (u_c - z_{ci}.w_{c,x})] = 0 \quad ..(13)$$

$$M_{b,xx} + F_{b,xx}..z_{bi} - k_{n2}(w_c - w_b) + k_{n1}(w_b - w_a) = \rho_b \quad ..(14)$$

2.4 Basic differential equations

From the analytical model, the six independent differential equations (equilibrium and compatibility), may be expressed in terms of displacement variables, $(u_a, w_a, u_b, w_b, u_c)$ and (w_c) as follows:

Assuming plane sections within each material remain plane, the axial strain (ε) can be expressed in terms of displacements $(u\ ,w\ )$ relative to the local x and z –axes, which are assumed to pass through the centroid of the three materials. Hence:

$$\varepsilon_a = U_{at,x} = U_{a,x} - z_a.w_{a,xx} \quad ..(15)$$

$$\varepsilon_b = U_{bt,x} = U_{b,x} - z_b.w_{b,xx} \quad ..(16)$$

$$\varepsilon_c = U_{ct,x} = U_{c,x} - z_c.w_{c,xx} \quad ..(17)$$

These subscripts a, b and c denote the different layers. Subscript (x), denotes differentiation and (z) the distance form the origin of coordinates to the limits of the layers.

Stresses now can be related to strain via the material properties (E_a, E_b) and (E_c). For linear elastic materials (E_a, E_b) and (E_c) are constants, but for non-linear elastic and elasto-plastic materials, (E_a, E_b) and (E_c) are functions of strain.

The free strain due to shrinkage, temperature etc, is denoted by (ε_f), while the strain induced during the construction sequence, is denoted by (ε_r). Hence, if $(u\ )$ and $(w\ )$ are assumed to exclude the displacements corresponding, to (ε_f) and (ε_r), the stresses in the layers are given by:

$$\sigma_a = E_a(u_{a,x} - z_a.w_{a,xx} + \varepsilon_{ra} - \varepsilon_{fa}) \quad ..(18)$$

$$\sigma_b = E_b(u_{b,x} - z_b.w_{b,xx} + \varepsilon_b - \varepsilon_{fb}) \quad ..(19)$$

$$\sigma_c = E_c(u_{c,x} - z_c.w_{c,xx} + \varepsilon_{rc} - \varepsilon_{fc}) \quad ..(20)$$

The axial forces, (F_a, F_b) and (F_c), and moments (M_a, M_b), and (M_c) are obtained by integrating the stresses, multiplying by the appropriate lever arms, (z_a, z_b) and (z_c), in the case of moments over the cross section area of each layer denoted by (A_a, A_b) and (A_c). Hence:

$$F_a = \int \sigma_a.dA_a \quad ..(21)$$

$$F_b = \int \sigma_b.dA_b \quad ..(22)$$

$$F_c = \int \sigma_c.dA_c \quad ..(23)$$

$$M_a = -\int \sigma_a.z_a.dA_a \quad ..(24)$$

$$M_b = -\int \sigma_b.z_b.dA_b \quad ..(25)$$

$$M_c = -\int \sigma_c.z_c.dA_c \quad ..(26)$$

Substituting Eqs. (18), (18), (20) into equations (21) to (26) which gives:

$$F_a = \int E_a.(u_{a,x} - z_a.w_{a,xx} + \varepsilon_{ra} - \varepsilon_{fa})dA_a \quad ..(27)$$

$$F_b = \int E_b.(u_{b,x} - z_b.w_{b,xx} + \varepsilon_{rb} - \varepsilon_{fb})dA_b \quad ..(28)$$

$$F_c = \int E_c.(u_{c,x} - z_c.w_{c,xx} + \varepsilon_{rc} - \varepsilon_{fc})dA_c \qquad ..(29)$$

$$M_a = -\int E_a.(u_{a,x} - z_a.w_{a,xx} + \varepsilon_{ra} - \varepsilon_{fa}).z_a.dA_a \qquad ..(30)$$

$$M_b = -\int E_b.(u_{b,x} - z_b.w_{b,xx} + \varepsilon_{rb} - \varepsilon_{fb}).z_b.dA_b \qquad ..(31)$$

$$M_c = -\int E_c.(u_{c,x} - z_c.w_{c,xx} + \varepsilon_{rc} - \varepsilon_{fc}).z_c.dA_c \qquad ..(32)$$

IF (E_a, E_b), and (E_c) are constants, integration of eqs. (27) to (32) gives:

$$F_a = E_a.A_a.u_{a,x} + E_a.(\bar{\varepsilon}_{ra} - \bar{\varepsilon}_{fa}) \qquad ..(33)$$

$$F_b = E_b.A_b.u_{b,x} + E_b.(\bar{\varepsilon}_{rb} - \bar{\varepsilon}_{fb}) \qquad ..(34)$$

$$F_c = E_c.A_c.u_{c,x} + E_c.(\bar{\varepsilon}_{rc} - \bar{\varepsilon}_{fc}) \qquad ..(35)$$

$$M_a = E_a.I_a.w_{a,xx} \qquad ..(36)$$

$$M_b = E_b.I_b.w_{b,xx} \qquad ..(37)$$

$$M_c = E_c.I_c.w_{c,xx} \qquad ..(38)$$

The following are the six governing equations derived for three layer composite simply supported beam:

$$M_{a,xx} + M_{b,xx} + M_{c,xx} - F_{b,xx}.d_1 - F_{c,xx}.(d_1 + d_2) = \rho \qquad ..(39)$$

$$M_{a,xx} + M_{b,xx} + M_{c,xx} + F_{a,xx}.d_1 - F_{c,xx}.d_2 = \rho \qquad ..(40)$$

$$F_{a,x} + F_{b,x} + F_{c,x} = 0 \qquad ..(41)$$

$$F_{a,x} - k_{s1}[(u_a - z_{ai}.w_{a,x}) - (u_b - z_{bi}.w_{b,x})] = 0 \qquad ..(41)$$

$$F_{a,x} + F_{b,x} - k_{s2}[(u_b - z_{bi}.w_{b,x}) - (u_c - z_{ci}.w_{c,x})] = 0 \qquad ..(42)$$

$$M_{b,xx} + F_{b,xx}..z_{bi} - k_{n2}(w_c - w_b) + k_{n1}(w_b - w_a) = \rho_b \qquad ..(43)$$

Differentiating eqs. from (33) to (38) several times with respect to (x) and substituting the resulting eqs. into equations (39) to (43) which gives:

$$E_a.I_a.w_{a,xxxx} + E_b.I_b.w_{b,xxxx} + E_c.I_c.w_{c,xxxx} - E_b.A_b.d_1.u_{b,xxx} - E_b(\bar{\varepsilon}_{rb} - \bar{\varepsilon}_{fb})_{,xx}.d_1 - (d_1 + d_2).E_c.A_c.u_{c,xxx} - E_c.(d_1 + d_2)(\bar{\varepsilon}_{rc} - \bar{\varepsilon}_{fc})_{,xx} = \rho \qquad ..(44)$$

$$E_a.I_a.w_{a,xxxx} + E_b.I_b.w_{b,xxxx} + E_c.I_c.w_{c,xxxx} + E_a.A_a.d_1.u_{a,xxx} + E_a(\bar{\varepsilon}_a - \bar{\varepsilon}_a)_{,xx}.d_1 - d_2.E_c.A_c.u_{c,xxx} - E_c.d_2.(\bar{\varepsilon}_{rc} - \bar{\varepsilon}_{fc})_{,xx} = \rho \qquad ..(45)$$

$$E_a.A_a.u_{a,xx} + E_a.(\bar{\varepsilon}_{ra} - \bar{\varepsilon}_{fa})_{,x} + E_b.A_b.u_{b,xx} + E_b(\bar{\varepsilon}_{rb} - \bar{\varepsilon}_{fb})_{,x} + E_c.A_c.u_{c,xx} + E_c.(\bar{\varepsilon}_{rc} - \bar{\varepsilon}_{fc})_{,x} = 0 \qquad ..(46)$$

$$E_a.A_a.u_{a,xx} + E_a.(\bar{\varepsilon}_{ra} - \bar{\varepsilon}_{fa})_{,x} - k_{s1}[(u_a - z_{ai}.w_{a,x}) - (u_b - z_{bi}.w_{b,x})] = 0 \qquad ..(47)$$

$$E_a.A_a.u_{a,xx} + E_a.(\bar{\varepsilon}_{ra} - \bar{\varepsilon}_{fa})_{,x} + E_b.A_b.u_{b,xx} + E_b(\bar{\varepsilon}_{rb} - \bar{\varepsilon}_{fb})_{,x} - k_{s2}[(u_b - z_{bi}.w_{b,x}) - (u_c - z_{ci}.w_{c,x})] = 0 \qquad ..(48)$$

$$E_b.I_b.w_{b,xxxx} + E_b.A_b.u_{b,xxx}.z_{bi} + E_b.z_{bi}.(\bar{\varepsilon}_{rb} - \bar{\varepsilon}_{fb})_{,xx} - k_{n2}.(w_c - w_b) + k_{n1}(w_b - w_a) = \rho_b \qquad ..(49)$$

2.5 Numerical solutions

Equations (44) o (49) contain derivatives of third order in (u) and fourth order in (w), which can be expressed in finite (central) difference form using five node points, for example, the derivatives of (w) at node (n) can be expressed as:

$$w_{n,x} = \frac{w_{n+1} - w_{n-1}}{2.\Delta x} \quad ..(50)$$

$$w_{n,xx} = \frac{w_{n+1} - 2.w_n + w_{n-1}}{\Delta x^2} \quad ..(51)$$

$$w_{n,xxx} = \frac{w_{n+2} - 2.w_{n+1} + 2.w_{n-1} - w_{n-2}}{2.\Delta x^3} \quad ..(52)$$

$$w_{n,xxxx} = \frac{w_{n+2} - 4.w_{n+1} + 6.w_n - 4.w_{n-1} + w_{n-2}}{\Delta x^4} \quad .(53)$$

After expressing equations (44) to (49) in finite difference form, the complete solution system of algebraic equations, six degrees of freedom per node, can be solved for the unknown displacements at the nodes, and it required two external nodes at each end of the beam. In general, since the model is done for uniform-distribution load and to specify the boundary conditions, the point load P can be idealized as a uniform distribution load $\rho = P/\Delta x$, applied over single node spacing.

2.6 Boundary conditions.

Solution of the resulting set of algebraic equations requires the specification of boundary conditions. In general, the equations contain a derivative of fourth order required two external nodes to specify the boundary conditions at each end. However, if each external node is assigned six degree of freedom per node, twelve boundary conditions are required for each end of the beam and must be specified.

$w_c = 0$ at $x = 0$ when $x = L$ ..(54)

$w_{a,xx} = 0$ at $x = 0$ when $x = L$ ..(55)

$w_{b,xx} = 0$ at $x = 0$ when $x = L$ ..(56)

$w_{c,xx} = 0$ at $x = 0$ when $x = L$ ..(57)

$u_c = 0$ at $x = 0$ ..(58)

$u_{c,x} = 0$ at $x = L$ ..(59)

$u_{a,x} = 0$ at $x = 0$ when $x = L$ ..(60)

$u_{b,x} = 0$ at $x = 0$ when $x = L$ ..(61)

$V_a + V_b + V_c = R_r$ at $x = 0$ ..(62)

$V_a + V_b + V_c = R_l$ at $x = L$ ..(63)

$u_{a,xxxx} = 0$ at $x = 0$ when $x = L$ ..(64)

$u_{b,xxxx} = 0$ at $x = 0$ when $x = L$ ..(65)

$u_{c,xxxx} = 0$ at $x = 0$ when $x = L$ ..(66)

$U_{ab,x} = 0$ at $x = 0$ when $x = L$ ..(67)

Equation (62) and (63) express the conditions that the sum of the shear forces in the layers are equal to the support reaction R_r and R_l.

It is noted that the free strain due to shrinkage and temperature etc and strain induced during construction sequence are neglected

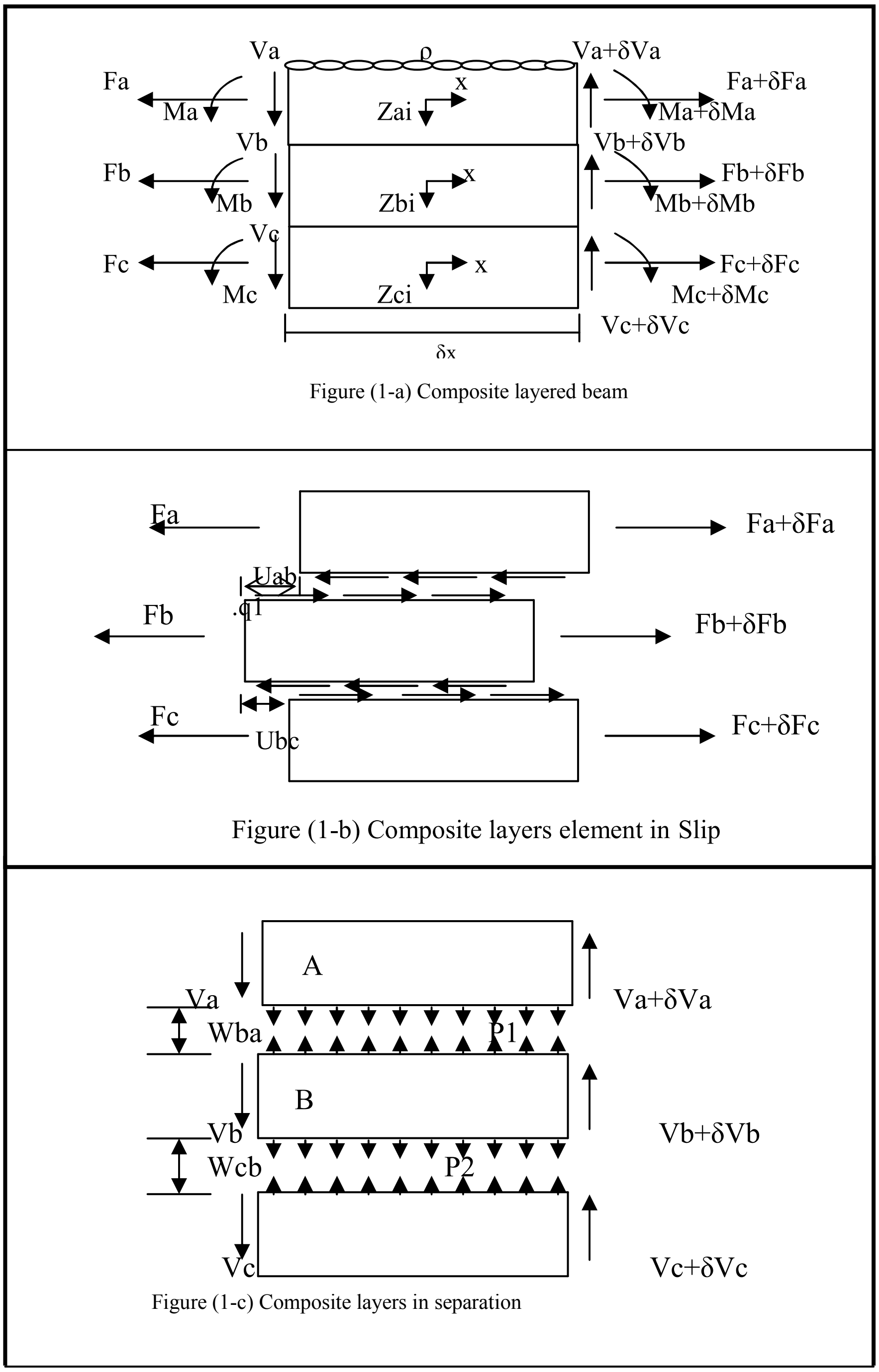

Figure (1-a) Composite layered beam

Figure (1-b) Composite layers element in Slip

Figure (1-c) Composite layers in separation

Figure (1) Composite three layer element

3.Experimental Tests

3.1 Materials

Experimental specimens include seven beams, each one consisting of three layers, details about each beam are shown in Figure (2) and Table(1) , each beam has two steel plates (upper and lower steel plates) confined a reinforced concrete layer. All these beams use a total width (200mm), and overall beam length (1500 mm), with clear span (1200mm). The concrete thickness, steel plate thickness, types of shear connectors and the distribution of shear connectors are variables. The stud connectors were welded to the tension and compression plates using electric welding, locatoin of studs shown in figure (2). The studs were arranged pairs per row. Prior to concreting, the internal surfaces of the steel plates cleaned carefully and the used polywood base oiled to prevent adheson. The steel plates and the oiled plywood base end forms were then clamped firmly together. Reinforcement are used in the concrete layer, longitudinal steel bar 10 mm diameter two at the top and at the bottom, also a series of rectangular stirrups were used to resist shear stresses. After concreteing the beams were covered with polythene sheet and cured in laboratory and site for 28 days prior to testing. Properties about the used concrete shown in Table(2) including laboratory tests for concrete cylinder specimens, compressive strength, tensile strength and modulus of elasticity .

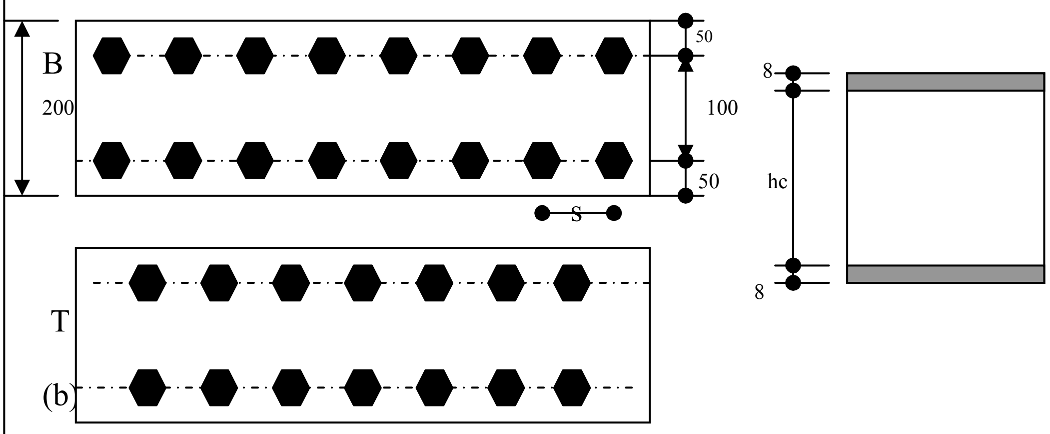

Figure (2) Dimensions of tested beams

Table (1) Specimens detail

No.	Stud dia. height (mm)	thickness of concrete (mm)	thickness of steel (mm)	Spacing For Studs (mm)	Ks (MPa)	As/Ac %
Beam 1	19mm ϕ h=100mm	250	8	150	Ks1=670	32
Beam 2	16mm ϕ h=85mm	250	8	120	Ks1	32
Beam 3	13mm ϕ h=65mm	250	8	85.75	Ks1	32
Beam 4	13mm ϕ h=65mm	250	8	120	Ks2=443	32
Beam 5	13mm ϕ h=65mm	250	8	150	Ks3=354	32
Beam 6	13mm ϕ h=65mm	200	8	85.75	Ks1	40
Beam 7	13mm ϕ h=65mm	300	8	85.75	Ks1	26

Table (2) Concrete properties

Beam No.	Compressive Strength $.f_{cu}$ MPa	fc= $0.85 fcu$ MPa	$.f_{ct=0.56}\sqrt{fc}$ MPa	Split Tensile $f_{ct} = \frac{2P}{\Pi.D.L}$ tests MPa
Beam 1	23.1	18.48	2.4	2.03
Beam 2	23.4	18.75	2.45	2.1
Beam 3	23.4	18.72	2.42	1.69
Beam 4	24.5	19.6	2.2	1.78
Beam 5	21.15	16.92	2.3	2.18
Beam 6	23.25	18.6	2.41	1.86
Beam 7	22.6	18.08	2.126	1.63

Three types of shear connectors were used, 13 mm diameter with height 65 mm, 16 mm diameter with height 85 mm, and 19 mm diameter with height 100 mm, headed stud. The steel plates, reinforcement and shear connectors were used in the beams tested by a universal testing machine, the standard specimen for this test was cut in a standard shape and details. Since there are three types of shear connectors its required to test the shear stiffness for each type, properties for the steel used in the tests are shown in Table (3).

Table (3) Properties of used steel

Types of steel	Yield stress MPa	Ultimate strength MPa	Elongation %	Young's Modulus of Elasticity *1000 MPa
Reinforcement (10 mm)	285	510	20	203
Connectors (13mm,16mm, 19mm)	275,285, 290	520,540,580	22,23,24	202
Steel plates	290	580	24	205

3.2 Push-out test specimens

A series of three push-out tests was performed on full-scale specimens having the same basic dimensions. Each specimens consist of (254mmx147mmx43mm UB) with (560mm long) connected to two (460mmx300mmx150mm) concrete slabs by means of two pairs of stud connectors, welded to both sides of the flange of the steel beam. Headed stud connectors are used for different diameter and length. The connectors have the following dimensions, 19-mm diameter with 100-mm length, 16-mm diameter with 85-mm length and 13-mm diameter with 65-mm length. The concrete slabs were reinforced with (10-mm) diameter reinforcing deformed steel.

The properties of standard shear connectors can be taken from references [5] and [6]. Since the shear connectors used in these tests were not standard it is required to obtain the real shear capacity for the connectors. Push out tests for each shear connector were made, for headed stud connectors, 19 mm diameter and 100 mm long, having ultimate shear capacity 125 kN, the secant shear stiffness for 50% of the ultimate load is 2025 kN/cm, corresponding to a slip of 0.0308 mm. For headed stud connectors, 16 mm diameter and 85 mm long, having ultimate shear capacity of 85 kN, the secant shear stiffness for 50% of the ultimate load is 1544 kN/cm, corresponding to a slip of 0.0264 mm. For headed stud connectors, 13 mm diameter and 65 mm long, having ultimate shear capacity of 60 kN, the secant shear stiffness for 50% of the ultimate load is 1063 kN/cm, corresponding to a slip of 0.0282 mm. Table (4)Figure (3) shows the relationship between the slip and shear capacity for the three types of connectors .

Table (4) Results of push-out tests.

ush out test	Stud Dimensions	50% ultimate load	Slip corresponding to 50% load
P1	D=19 mm H=100mm	62.5	0.0388
P2	D=16 mm H=85mm	42.5	0.0264
P3	D=13 mm H=65mm	30	0.0282

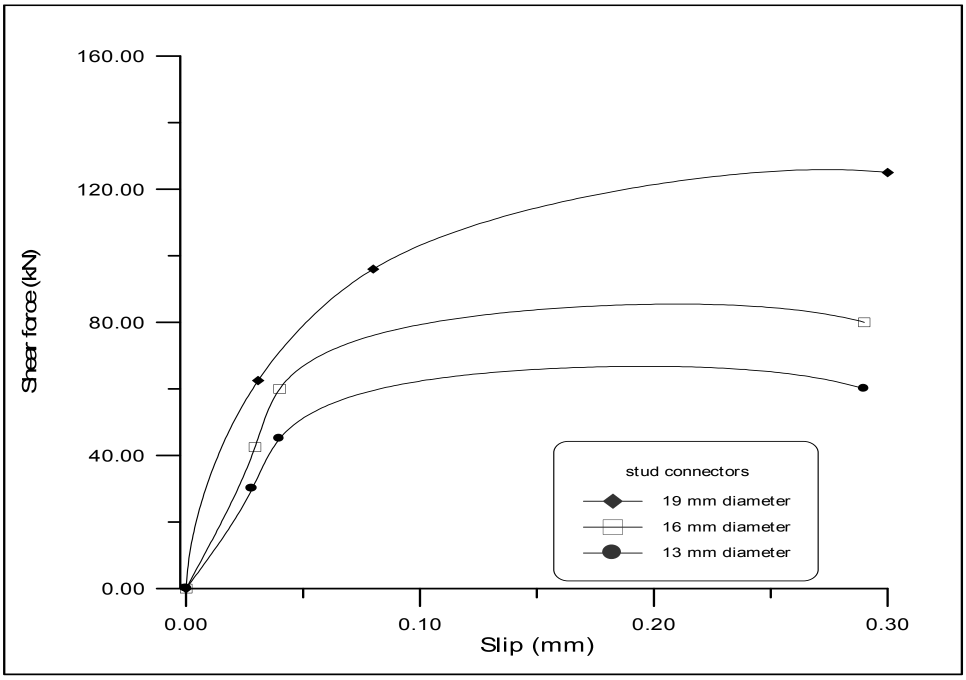

Figure (3)Push-out test for stud connectors

3.3 Testing

Load was applied to the top of composite beam by the cross head of the machine acting through a ball seating, care being taken each time in centering the load. The total duration of the test up to failure point is about (60 minute). If the specimen remained intact, loading was continued until severe cracking in the concrete layer occurred. Horizontal slips between layers were measured by means of dial gauge reading to (0.01 mm). The dial gauges fixed at the interface layers at half span for slip and under the beam for deflections.

Measurable slip and deflections occurred when the first increment of the load was applied. The failure is usually recorded by horizontal cracking of the concrete layers about (60-80)% of the ultimate load. Measurements of the slips and deflection in all tests are plotted for different shear stiffness. Also, the slips and deflections are plotted for different layer thickness.

4.Comparison with experimental work

The results obtained by experimental tests, are compared with the numerical solutions obtained from the program based on present model. Two variables mainly affect the behavior of multi-layer composite beams , these variables are the slip between layers and deflection , which are measured experimentally.

Figure(4) shows the variation of the deflection for lower layer along the beam for different shear stiffness values . It can seen that the value obtained from the experimental tests are in close agreement by about 1.0-2.5% with the theoretical values. When shear stiffness increases deflection decrease due to increase of interaction between layers, and the deflection in this case approaches the value of deflection for full-interaction beam when the shear stiffness increase to very high value (full-interaction)

Figure (5) and Figure (6) shows the variation of upper interface slip and lower interface slip along the beam. It can seen that the value of slip in upper and lower interface slip must be same since the upper and lower shear stiffness are same. But the experimental work gives a relatively close value . When the shear stiffness increases , slip decreases since the movement between layers is constrained and the studs become strong enough the resist the shear stress. The experimental tests are in close agreement by about 1.0% with the numerical values.

Figure(7) shows the variation of the deflection for lower layer along the beam for different cross-sectional areas . It can seen that the value obtained from the experimental tests are in close agreement by about 1.5-2.5% with the theoretical values. When As/Ac increases deflection decrease since the deflection is a prosperity of the whole cross section.

Figure (8) and Figure (9) shows the variation of upper interface slip and lower interface slip along the beam for different layer thickness The experimental values gives a close agreements with the numerical values by about 2.5-12.5 % , and the figures shows that when As/Ac increases slip decreases . All the beams were tested under simply supported conditions with linear materials and shear connector behavior

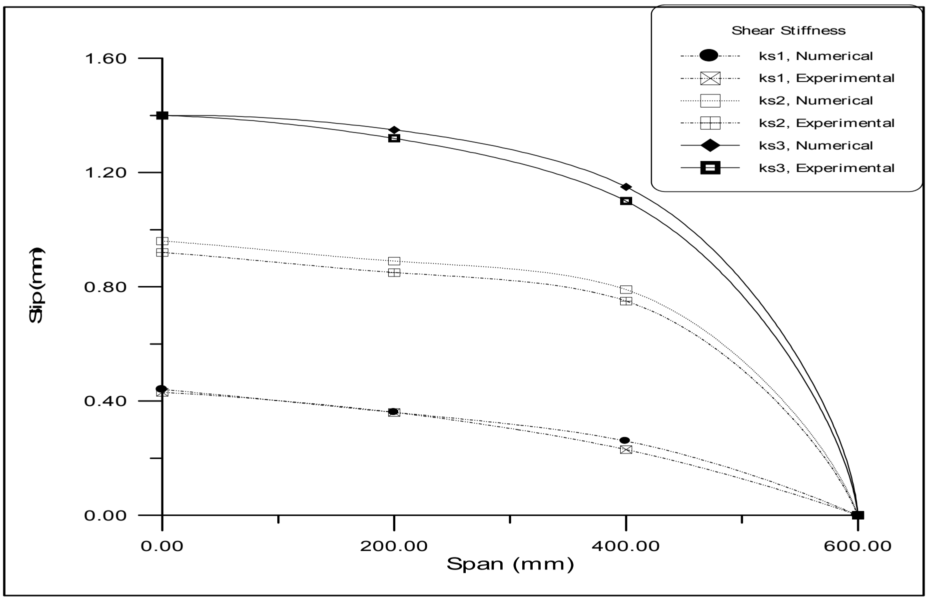

Figure (4) Deflection along the beam for different shear stiffness

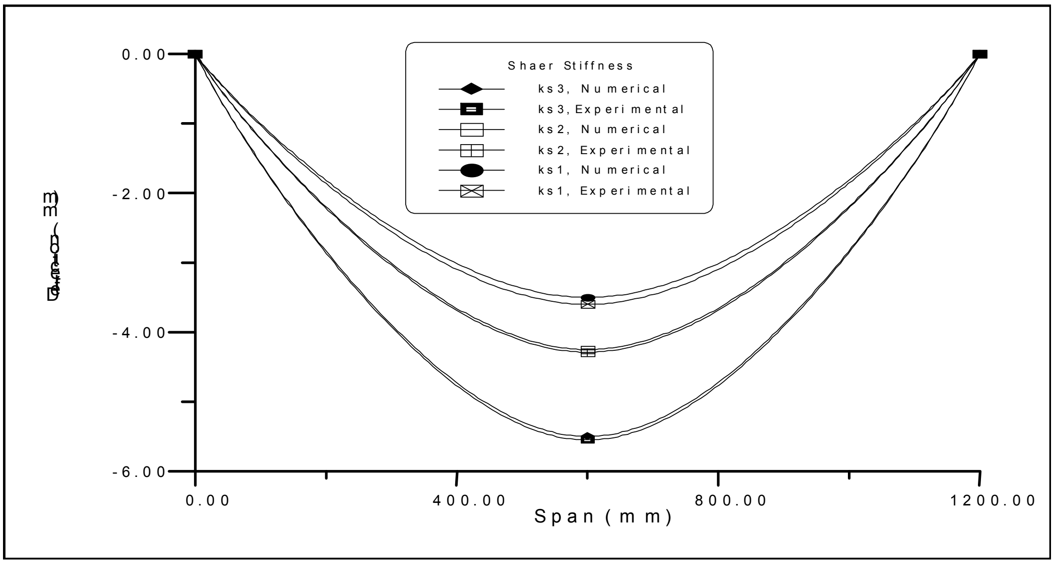

Figure (5) Variation of slip1 along the beam for different shear stiffness

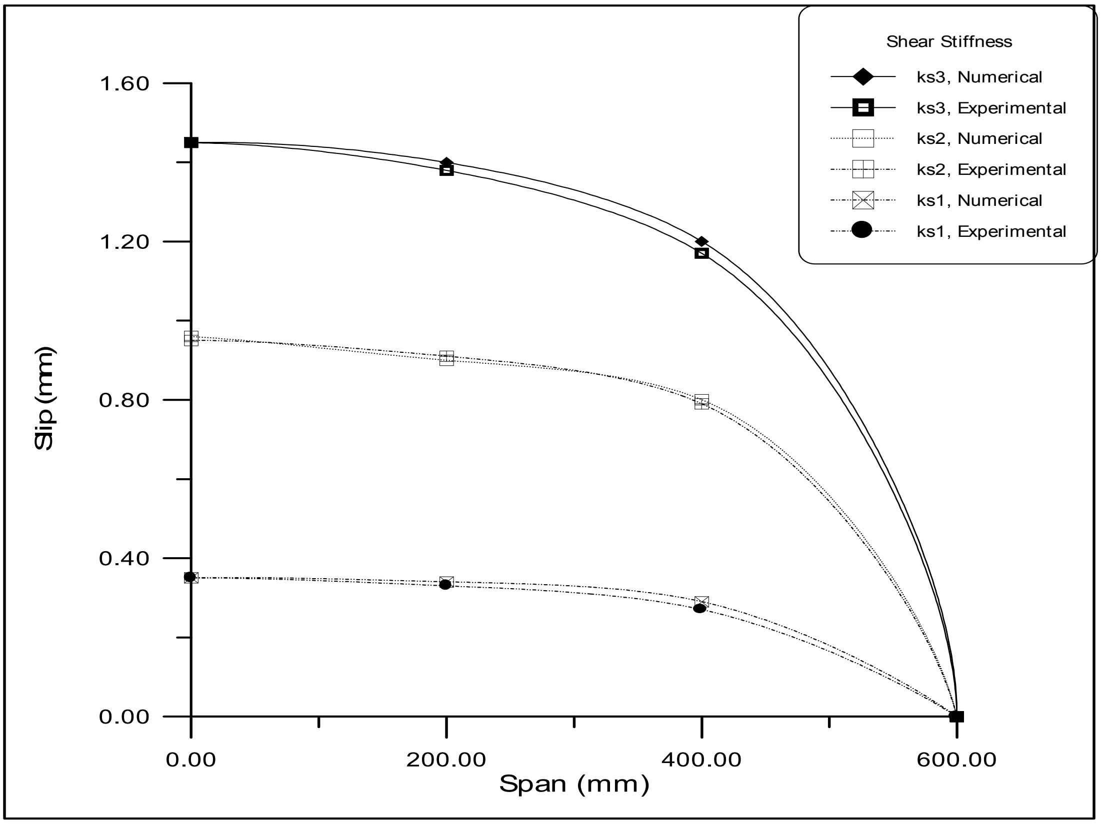

Figure (6) Variation of slip2 along the beam for different shear stiffness

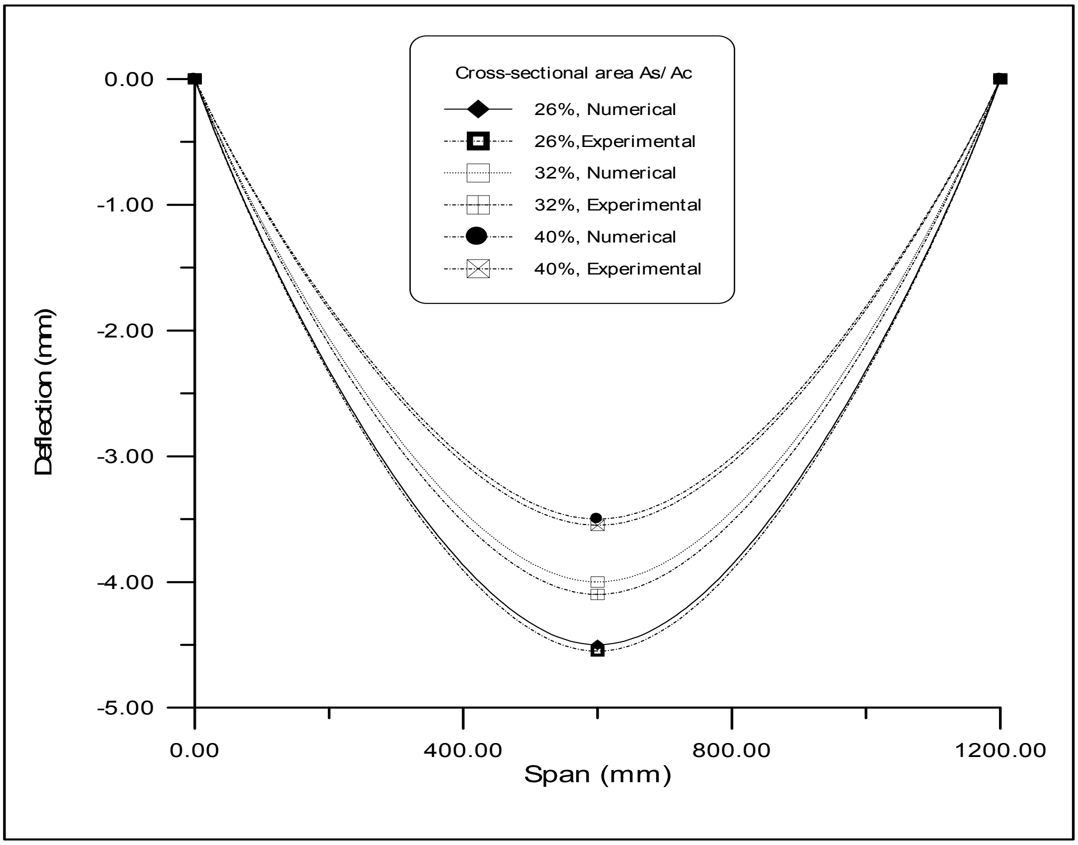

Figure (7) Deflection along the beam for different layer thickness

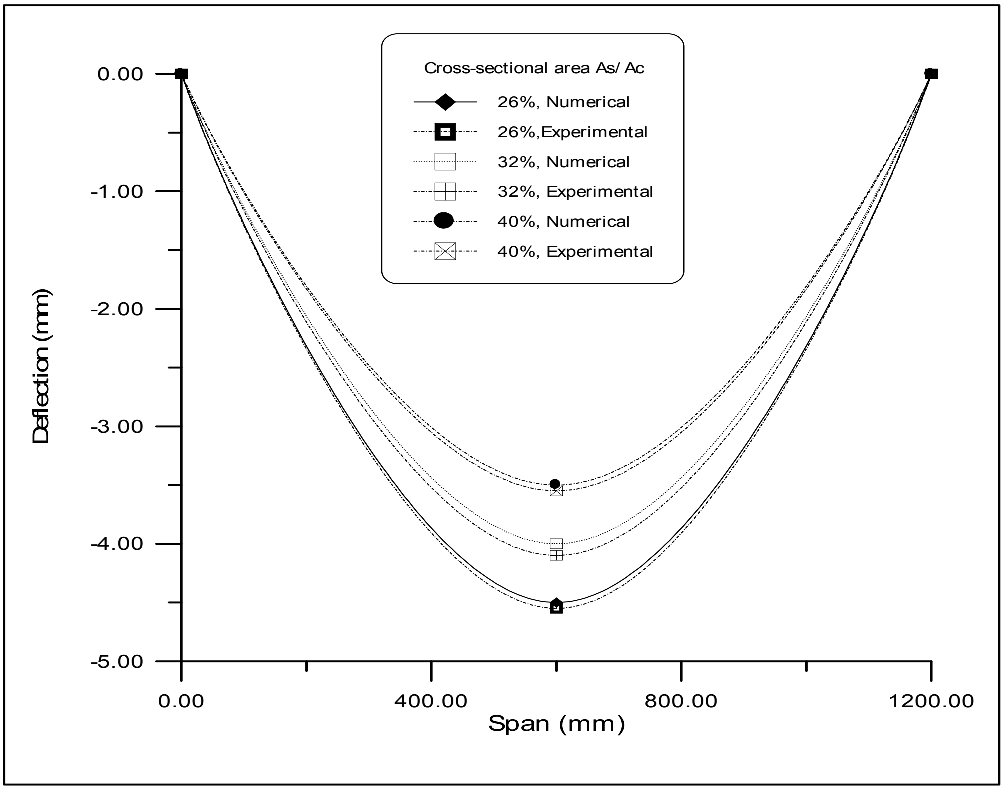

Figure (8) Variation of slip1 along the beam for different layer thickness

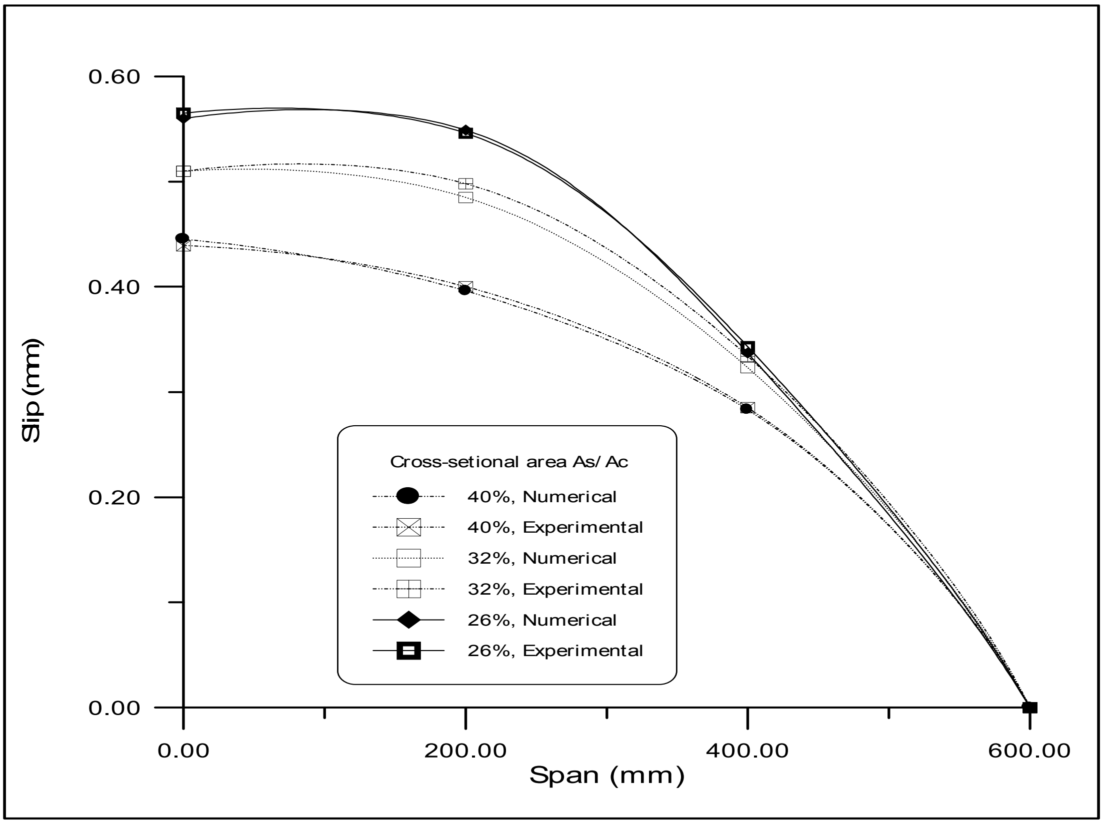

Figure (9) Variation of slip1 along the beam for different layer thickness

CONCLUSION

Composite multi-layered beam is relatively new construction and can be used in many industries besides strengthening a damaged or weaken construction and the main problem is the relative movement between layers which is handed in the present analysis The theory developed can be used in other branches of engineering specially mechanical engineering since the material properties and types of connectors are not specified and the shear stiffness is assumed to be continuous over the whole beam. A theory of three layer composite simply supported beams based on Roberts' approach led to six differential equations with a computer program to solve these equations is presented in this paper. Three push out test beside seven three layers composite beams are made and the results compared with a computer program based ob the theoretical approach which gives a close agreements.

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