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Analysis Up To Failure of Straight and Horizontally Curved Composite Precast Beam and Cast-In-Place Slab with Partial Interaction

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Abstract

In this study, a nonlinear three dimensional finite element analysis has been used to conduct an analytical investigation on the behavior of curved in plan composite concrete-concrete beam using the analysis system computer program (ANSYS v.9.0 2004).

Various types of beams, with available experimental results are chosen to check the validity and the accuracy of the adopted models. In general good agreement is obtained. The maximum percentage difference in ultimate load-carrying capacity is 12%. Parametric studies are carried out to study the influence of the curvature (L/R ratio of 0, 0.1, 0.15 and 0.2) on the behavior of the curved in plan composite concrete beams. Also, some important material and solution parameters that affect the structure behavior are studied. These include the slab thickness, support condition, compressive strength of concrete and the percentage of steel across the interface between the stem and the slab of the composite beam.

Keywords: Concrete-Concrete composite beams, Beams curved in plane, Finite element analysis.

التحليل لحد الفشل للعتبة المركبة المنحنية افقيا و المتكونة من رافدة كونكريتية مسبقة الصب و سقف مصبوب موقعيا مع التداخل الجزئي

الخلاصة

في هذه الدراسة تم استعمال طريقة العناصر المحددة ثلاثية الأبعاد لاخطية لتقصي سلوك العتبات المقوسة افقيا المركبةمن كونكريت-كونكريت بالاستفادة من برنامج ANSYS (الاصدار التاسع2004).

تم تحليل أنواع مختلفة من العتبات الخرسانية المسلحة ذات نتائج عملية متوفرة لتقويم النماذج و الطريقة المستخدمة في هذه الدراسة.بصورة عامة أعطت المقارنة توافق جيد,واكبر فرق في التحمل الأقصى للعتبات جاءت 12%. تمت دراسة تأثيرالتقوس(نسبة L/R لقيم 0.15,0.1, 0 و 0.2) في العتبات الخرسانية المركبة المقوسة افقيا على السلوك و الحمل الأقصى لهذه العتبات, كما تمت دراسة تأثيرات خواص المادة المهمة و بعض العوامل المستخدمة في التحليل على سلوك العتبات والتي تتضمن سمك السقف,مقاومة الانضغاط، طبيعة الإسناد و تأثير كمية الحديد الذي يمر خلال الوجه البيني الذي تلتقي فيه شفة العتبة مع الوترة .

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1. Introduction

In structural engineering practice, composite construction consists of two or more components connected together in one structural unit, so that each component is used to its best advantage. The most common material combinations are steel and concrete, timber and concrete and precast and cast-in-place concrete.

A composite concrete beam is a built-up member. Some composite concrete structures are made from the combination of precast concrete beam and cast in place deck [1]. The structural stem is usually made of a material, which carries tensile stresses efficiently, while the concrete slab has good compressive strength. The shear connectors between the stem and the slab should tie the two components together well enough so that they act as a monolithic beam such as the case for short to middle span bridges. Common sections of composite reinforced concrete flexural beams used for buildings and bridges are shown in Fig. (1).

A longitudinal shear flow in a composite concrete beam is transferred across the stem-slab interface by the dowel action of steel bars and by friction at the contact concrete surfaces.

The steel bars passing through the built-in interface of the composite concrete beam, may act as shear connectors. Moreover, they have their ability to hold the slab down against the beam and prevent the uplifting of the slab.

2. History of work:

Hanson [2] adopted push-off tests for studying the construction joints of composite concrete-to-concrete beams. For the problem of shear connections between precast beams and cast-in-place slabs, results of these preliminary tests indicated that the ultimate horizontal shear strength of a smooth bonded joint was about 2.0 MPa and that of a rough bonded joint was 3.4 MPa. In addition, it was found that the shear strength of a joint could be increased approximately by about 1.2 MPa for each percent of reinforcing steel crossing the joint.

Tests were carried out at the Imperial Collage of Science and Technology, London University, by Revesz [3] on five different composite T-beams to determine the behavior of the beams under loads. The test load was applied at third-points of the (4.25 m) beam specimens. The particular shape of the section was chosen so as to represent a strip of floor construction. The precast web consisted of a high quality concrete core (152.4 mm) deep and (76.2 mm) wide, encased in nonstructural precast foamslag plank. Reinforcement in four of these beams consisted of (2.6 mm) diameter high tensile strength wire, tensioned to various stresses. For comparison, one beam was reinforced with mild steel. It was concluded that the variation in the quality of the cast-in-place concrete of T-beams does not exert appreciable influence on the load capacity of composite beams, and it is desirable to roughen contact surfaces of the precast web and cast-in-place concrete of composite beams, to prevent failure by horizontal shear.

In 1978, Thomas et al.[4] studied the behavior of reinforced concrete horizontally curved beams. They tested seven horizontally curved reinforced concrete beams with cross section (152.4*304.8)mm and a radius of (2740mm) and a subtending angle of 90o, fixed at both ends. The beams were subjected to a concentrated load at mid-span. The results showed that the conventional design of horizontally curved reinforced concrete beams is suitable to calculate the flexure moments, torsion moments and the shear forces by an elastic analysis using the uncracked cross section. Since moment redistribution occurs after cracking, design of curved beams using cracked section is then recommended particularly near supports where torsional moment changes rapidly along the length. Torsional moments in a horizontally curved beam are primary moments required by equilibrium. They cannot be reduced or neglected.

In 1993, Thannon[5] proposed a fully three dimensional finite element computational model for the nonlinear analysis of a reinforced concrete curved beam. The twenty-noded isoparametric elements were used with the standard derivation of the stiffness matrix. Complete bond between the steel and the surrounding concrete was assumed. The model was used to analyze reinforced concrete beam curved in plan and loaded by a concentrated force which was tested by others. The result shows good agreement between the test and the proposed model.

3. Materials Idealization:

• SOLID65 element

8-node isoparametric linear brick element is used, in this study, to simulate the behavior of concrete beam and slab. Each of the eight corner nodes has three degrees of freedom, displacements u, v and w in x, y and z directions, respectively [6] ,Fig.(2) .

• Reinforcement Idealization

In the present research, the reinforcing steel bars are modeled as axial members embedded within the concrete brick elements (embedded representation) to include the reinforcement effect in the concrete beam and slab, excluding the reinforcing bars that are crossing the joint, which are represented by using “bar elements” (Discrete representation). In these two manners, the reinforcement is assumed to be capable of transmitting axial forces only, and perfect bond is assumed to exist between the concrete and the reinforcing bars ,Fig.(3) .

• LINK8 Element

This element is used to simulate the function of shear connectors in transferring the normal force between the concrete beam and the slab and resisting the uplift separation,Fig.(4) .

• COMBIN39 Element

This element is used to simulate the function of the shear connectors in resisting the horizontal shear between the concrete beam and the slab and resisting the slip ,Fig.(5) .

• Shear-Friction and Contact Modeling

A three dimensional point-to-point contact element from ANSYS is used to model the nonlinear behavior of the surface between two concretes cast at different times. The contact elements are capable of supporting only compression in the direction normal to the interface between the two surfaces and shear- friction in the tangential direction ,Fig.(6) .

4. Materials Properties

- **Modeling of concrete**

The concrete is assumed to be homogeneous and initially isotropic. The compressive stress-strain relation is described by an elastic-perfectly plastic brittle fracture model ,Fig.(7) .

- **Modeling of Cracked Concrete**

The crack of concrete is modeled as "a smeared crack model". In this approach, it is assumed that the concrete becomes orthotropic after the first cracking has occurred with reduced modulus of elasticity in the direction normal to the crack plane[7] ,Fig.(8) .

- **Modeling of Steel Beam and Reinforcement**

The steel can be considered as a homogeneous material .The simplest and the most commonly used idealization of the stress-strain curve is the elastic-perfectly plastic relation which ignores the strain hardening region as shown in Fig.(9) [8].

Modeling of Shear Connectors When composite beams deform under external vertical loads ,effective shearing forces are developed that act on the planes of contact .Shear force will be transferred by means of friction and the dowel action of crossing bars. The normal forces are transmitted by the axial forces in the reinforcing bars and are modeled using "link elements". While the shear forces that are transmitted by shearing and flexure of the crossing bars are modeled by using "nonlinear spring elements". When the bars are being normal to the plane of joint, dowel action (shearing and flexure of the bars) will contribute to the overall shear stiffness throughout the joint. The nonlinear shear stiffness of the dowel bars is given by [9]:

$$K_s = \frac{F_d}{\Delta U_s}$$

where :

F_d , is the dowel force and given by

$$F_d = F_{du}\left(1 - e^{\frac{-k_i \ \Delta U_s}{F_{du}}}\right)$$

F_{du} , is the ultimate dowel force, in (N) $= 1.3\phi^2\sqrt{1.2 \ f_c' \ f_y}$

k_i , is the initial dowel stiffness

$= 0.166 \, \Delta U_s \, G_f^{0.75} \, \phi^{1.75} \, E_s^{0.25}$

G_f , foundation modulus of concrete and

it is $G_f = 750 \text{ N/mm}^3$ for $1.2 f'_c \leq 35$ Mpa

ϕ , is the stud diameter.
E_s, elastic modulus of steel stud, in (Mpa).

5. Numerical application

In order to assess the validity and accuracy of the finite element procedure, using ANSYS computer program (v.9.0 2004),two composite concrete beams are selected, which were experimentally tested by Grossfield and Birnstiel [10] .In this study, comparison of the load-deflection behavior and the ultimate load between the finite element analysis and the experimental tests were carried out.

- **Description of Beams**

Two straight composite concrete-concrete beams are chosen for the finite element analysis, one is (Beam 1) of Type A and the other is (Beam 2) of Type B ,Fig.(10). These two composite beams had their flanges cast to the web after the latter had been cured and the joint treatment was troweled smooth .A typical beam is shown in Fig(11). It is simply supported over (3048 mm) span and the external load was applied to the speciments at two points.

In Type B,the area of steel joining the web and flange of the beam is twice as that in Type A. Therefore, the steel ratio across the joints of Types A and B is kept constant and has a value of (0.0088).

In general good agreement was obtained between the present finite element and the experimental results.The maximum different in ultimate loads was (12%).The ratio of Pu (Analytical) to Pu (Experimental) for (Beam 1) Type A is (0.88) and the ratio of Pu (Analytical) to Pu (Experimental) for (Beam 2) Type B is (0.95),Fig.(12).

6. Parametric Study

A parametric study was performed to investigate the influence of several important parameters on the behavior of horizontally curved composite concrete-concrete beams.

- The effect of curvature (L/R) of the beam(L=arc length and R=radius).
- Effect of supports condition.
- Effect of compressive strength of concrete ($f'c$).

Effect of Curvature(L/R)of the beam

In the current study, (beam 2) Type B (SP1) has been chosen in a numerical study to demonstrate the effects of curvature on the nonlinear behaveor of the beam.

Based on the results of the analysis, the following observation may be noted:

- With respect to the straight beam SP1(L/R =0), the effect of L/R =0.1, in designated beam SP2, resulted in reduction of the ultimate load by (23%).
- Similarly, the effect of L/R=0.15, in designated beam SP3 resulted in reduction of the ultimate load by (37%).
- Also, the effect of L/R=0.2, in designated beam SP4 resulted in reduction of the ultimate load by (40%).

Fig.(13) shows the load-deflection curves for various L/R ratios.

And, the beam (SP2) where L/R = 0.1 has been employed in a numerical study to demonstrate the effects of some parameters on the nonlinear behavior. These parameters include the following:

- Effect of support condition.
- Percentage of steel across the interface.
- Effect of compressive strength of concrete.
- Effect of the slab thickness.

Fig. (14) shows the finite element mesh with the boundary and loading conditions of beam (SP2) .

Effect of Support Condition

- With respect to the hinge-roller supports (simply supported ends), the fixed-roller support increased the ultimate load by (5.2%).
- Similarly, fixed end support increased the ultimate load by (61%).

Fig.(15) shows the effect of various support conditions.

Effect of Percentage of Steel across the Interface

Two different percentages have been considered in order to investigate the effect of steel crossing the interface on the behavior of the horizontally curved composite concrete-concrete beams. It is noted that:

- 35% increase of steel ratio caused an increase of 4% in the ultimate load capacity while 36% decrease of steel ratio caused a decrease of 10% in the ultimate load capacity with respect to the original crossing steel in beam SP2.
- The results concerning this effect on the load-slip response show that an increase by 35% of the crossing steel ratio caused a decrease of 26% in maximum slip and a decrease by 36% of the crossing steel ratio caused an increase of 38% in the amount of slip.

This effect on the load-deflection and load-slip response is shown in Figs. (16) and (17).

Effect of Compressive Strength of Concrete:

- With respect to the beam SP2 with originally $f'c$=30 MPa, the effect of $f'c$=25 MPa, caused a decrease in the ultimate load by about (16.8%).
- Similarly, the effect of $f'c$=35 MPa, caused an increase in the ultimate load by about (10.3%).

Fig. (18) shows the effect of $f'c$ on the load-deflection curve.

Effect of Slab Thickness:

- With respect to the original s lab thickness (105mm), when the thickness h= 120 mm is used, the ultimate load is increased by (7.4%).
- Similarly when h=140 mm is used, the ultimate load is increased by (17.3%).

Fig. (19) shows the effect of slab thickness on the load-deflection curves.

7. Conclusions:

- Based on the results of the available experimental tests on straight composite concrete-concrete beams, the comparison with the results from the present finite element analysis by (ANSYS),has shown that the adopted computer modeling can be used efficiently to predict the behavior of such composite beams.

- It is found that the ultimate load capacity decreases with increase in L/R ratio in curved -in- plan composite beams. With increase in L/R ratio up to 0.2 the main cause of failure changes from dominant bending to combined action of bending and twisting.
- The results for fixed end beam and fixed-roller beam indicate an increase in ultimate load in comparison to a simply supported beam.
- When the percentage of steel across the interface increases the ultimate load increases and the amount of slip at the interface between the concrete slab and the precast beam (maximum near ends) decreases.
- Increasing the compressive strength of concrete causes an increase in the ultimate load carrying capacity.
- It is found that increasing the slab thickness causes an increase in the load-carrying capacity.

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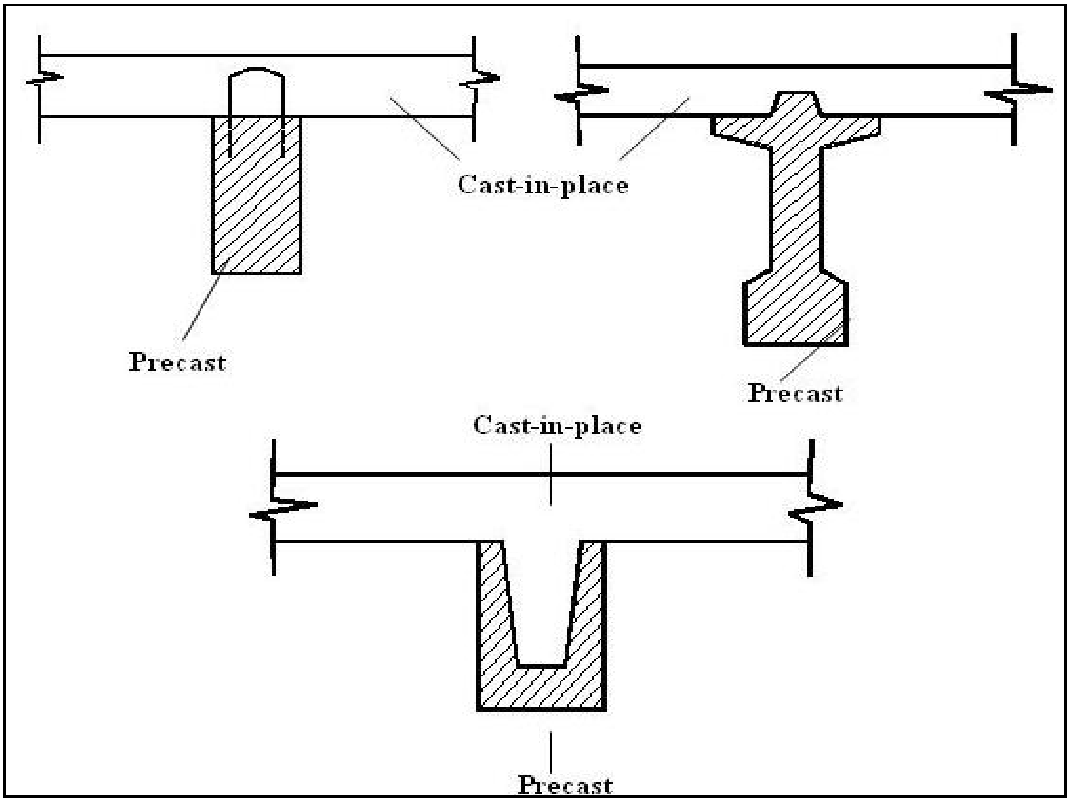
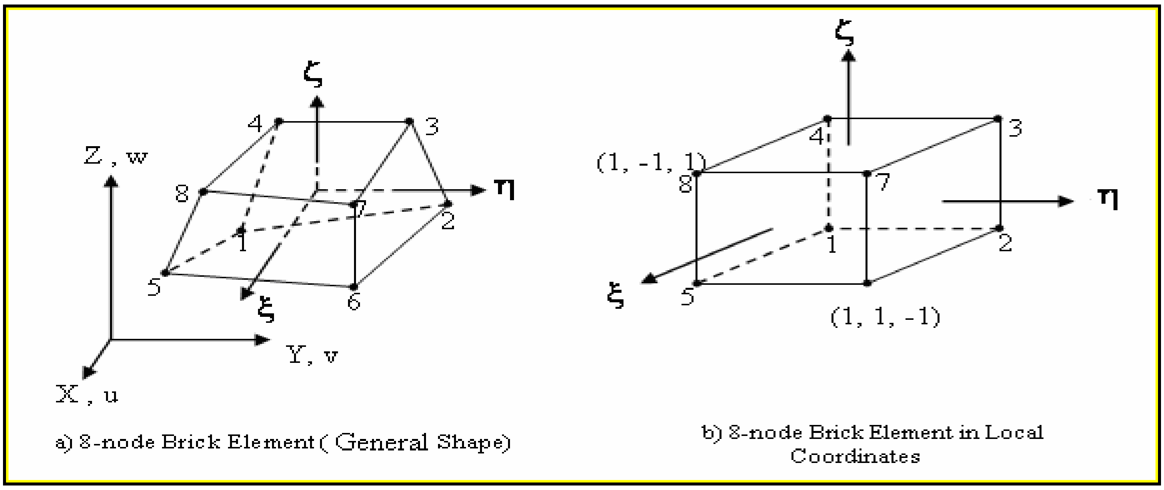


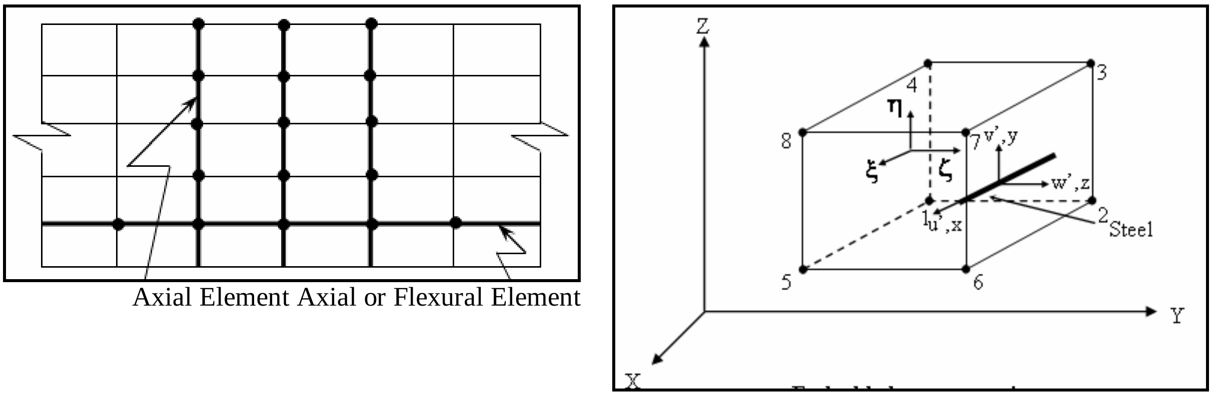
Figure (1): Common sections of composite concrete structures[1].



a) 8-node Brick Element (General Shape)

b) 8-node Brick Element in Local Coordinates

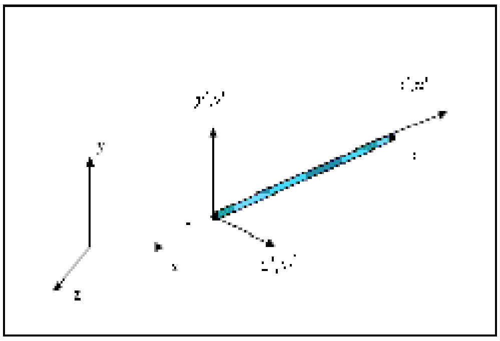
Figure (2): Brick element with 8-nodes (Solid65 in ANSYS) [6].



Discrete representation

Embedded representation

Figure (3): Reinforcement idealization[6]



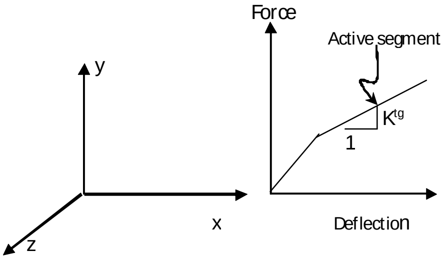


Figure (4):Bar element (Link8 in ANSYS) [6]

Figure (5): Nonlinear spring element(Combine39 in ANSYS) [6]

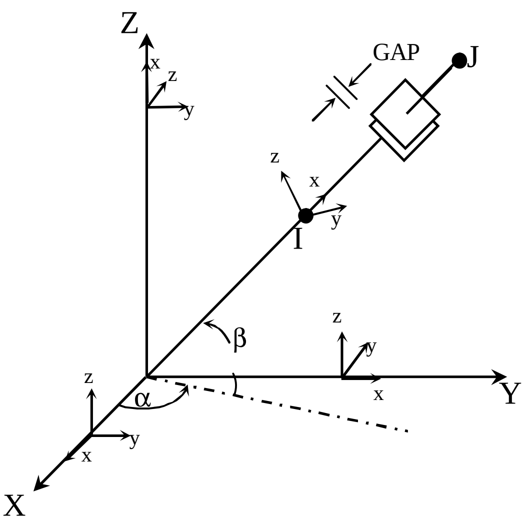


Figure (6): Geometry of Contact173 [6].

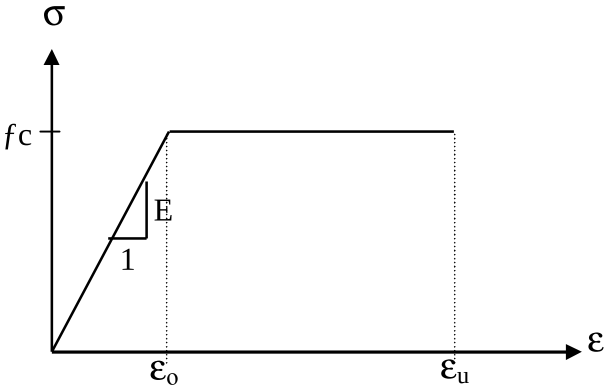


Figure (7): Uniaxial stress-strain relationship used for concrete[6].

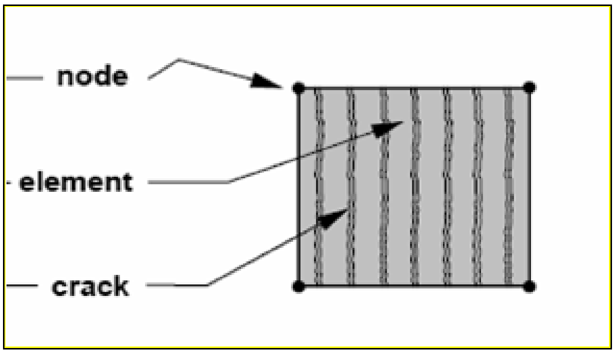


Figure (8):Smeared crack modeling.

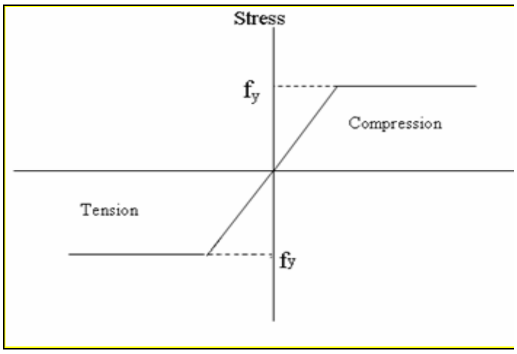


Figure (9): Idealized bilinear stress-strain curve for steel

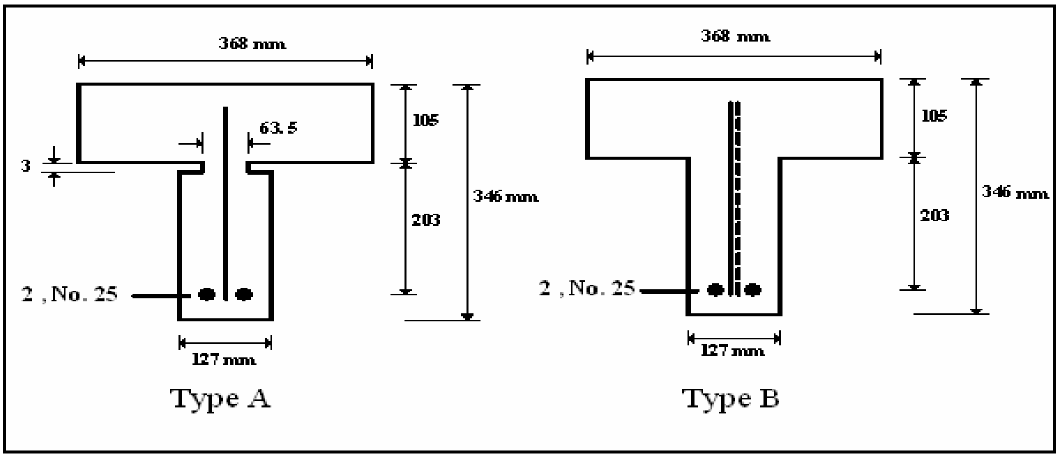


Figure (10):Dimensions and reinforcement details of beams[10] .

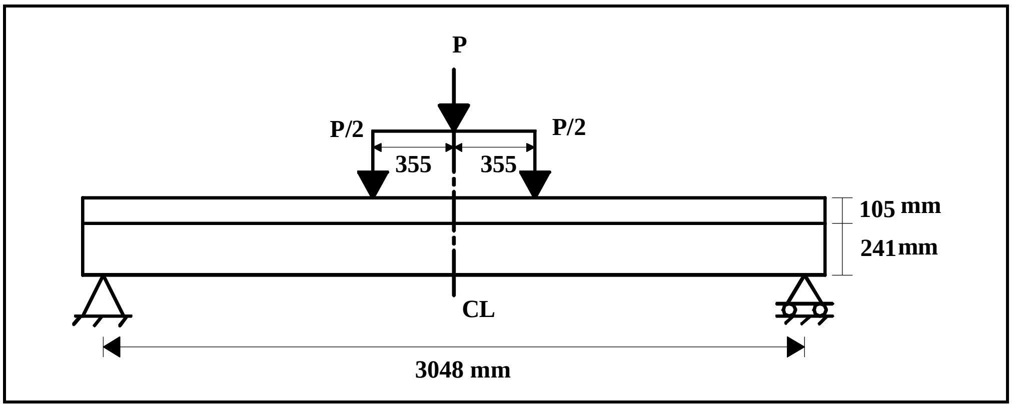
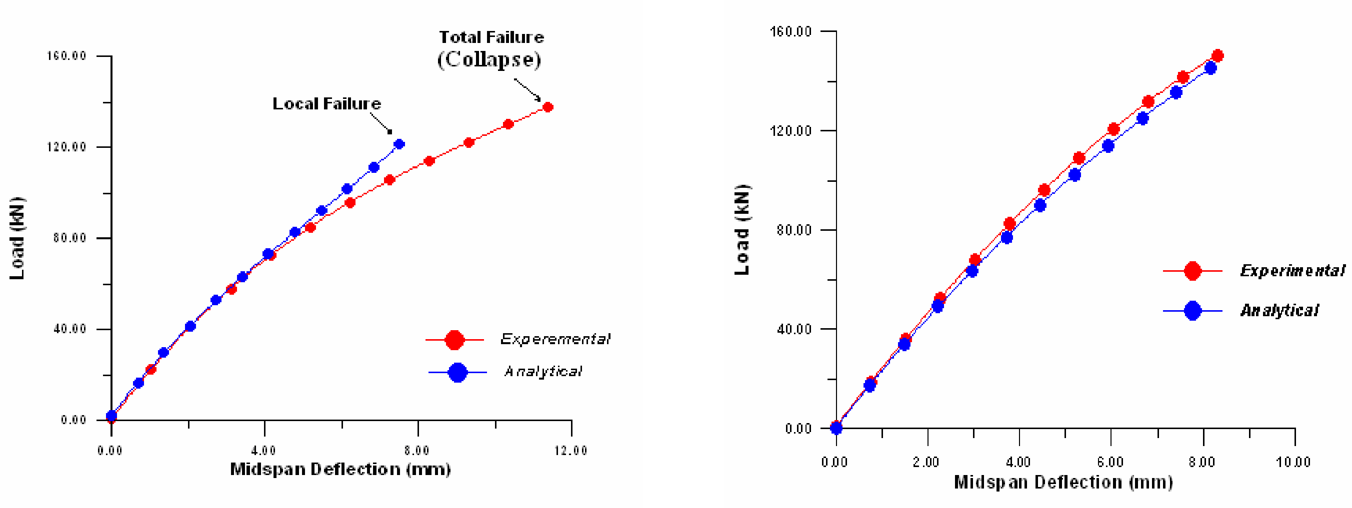


Figure (11):Dimensions and loading arrangement of a typical Grossfield-irnstiel beams[10]



Load-deflection behavior of (Beam 1) Type A

Load-deflection behavior of (Beam 2) Type B

Figure (12): Load-vertical displacement curves of composite beams.

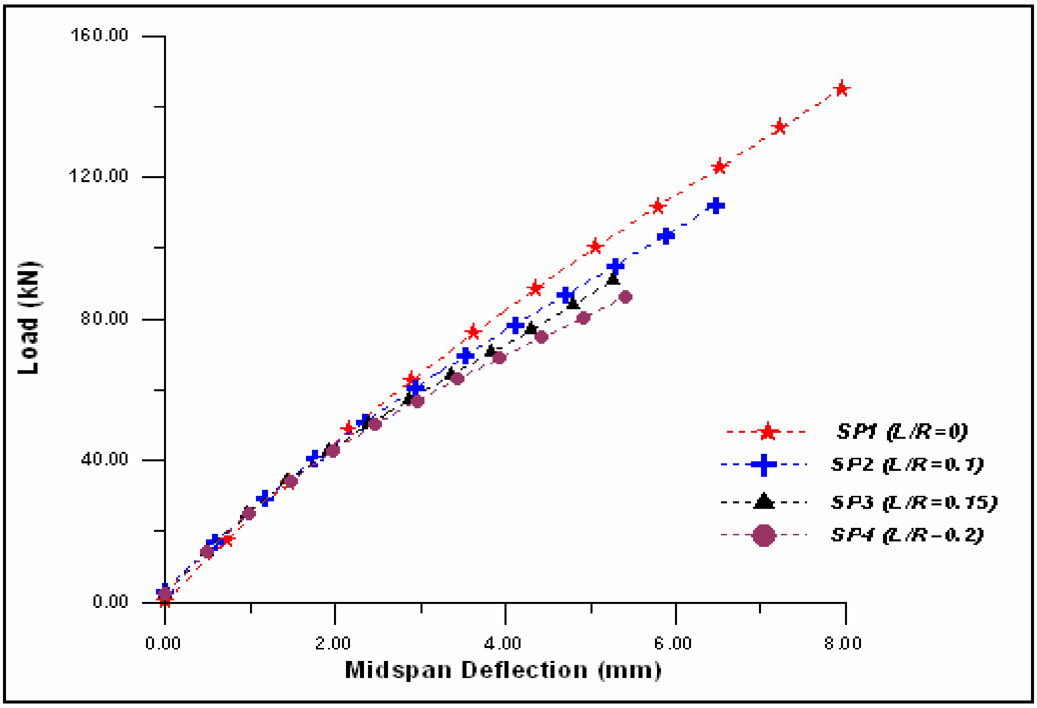


Figure (13):Load-deflection curves of composite beams SP1,SP2,SP3,and SP4.

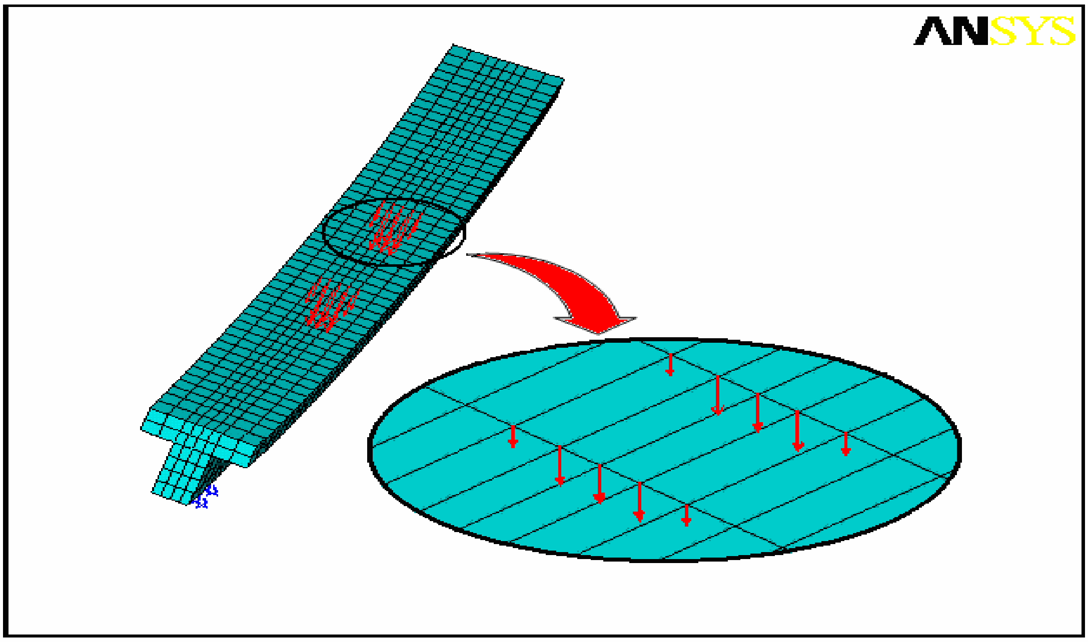


Figure (14): Finite element mesh with boundary and loading conditions of beam (SP2)

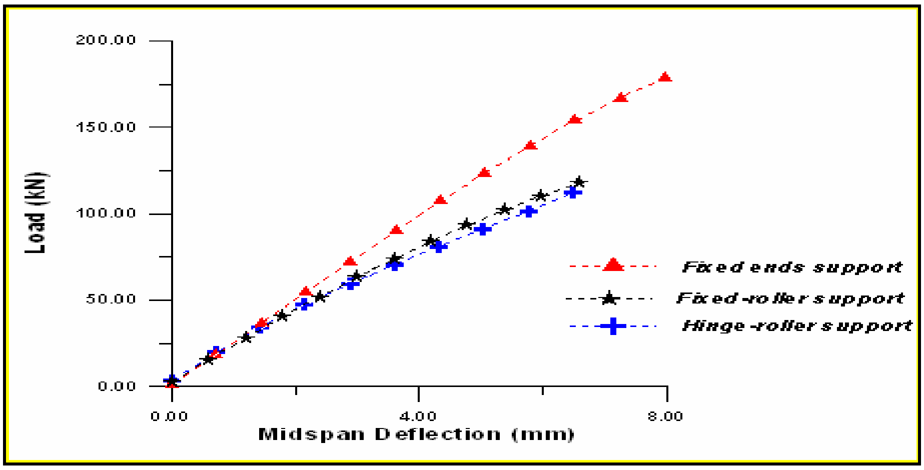


Figure (15): Load-deflection curves of composite beam SP2

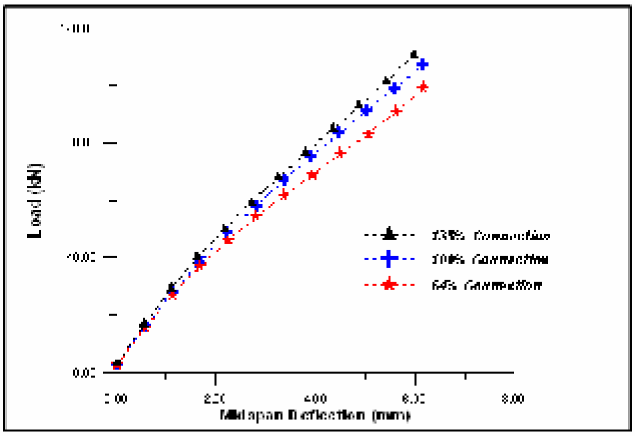


Figure (16): Effect of percentage of steel across the interface on the load-deflection curves of composite beam SP2

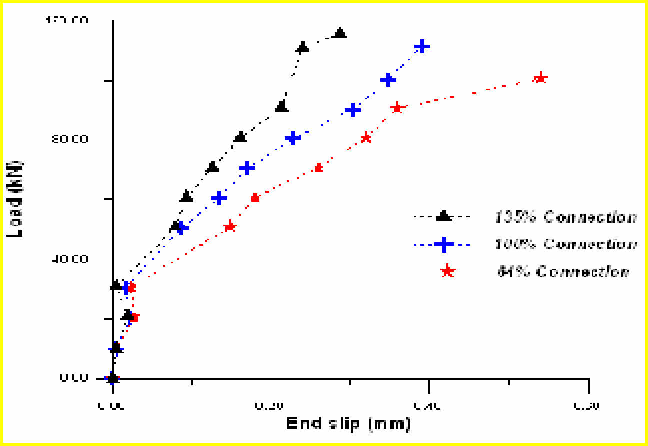


Figure (17): Effect of percentage of steel across the on load-slip curves of composite interface beam SP2.

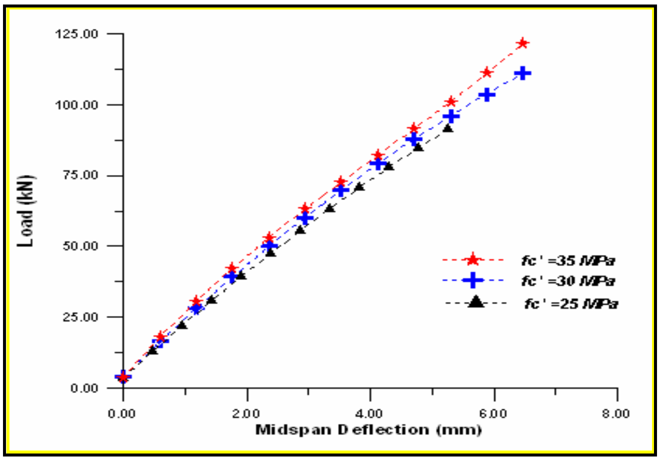


Figure (18): Effect of ($f'c$) on load-deflection curves, Beam SP2

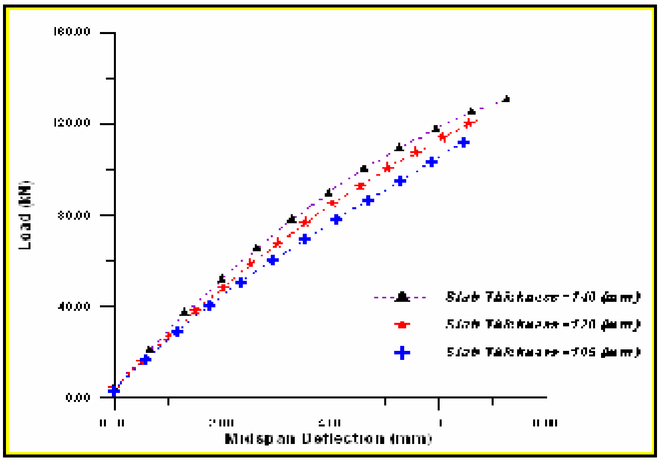


Figure (19): Effect of slab thickness on the load-deflection curve, Beam SP2