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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 predict the load-deflection behavior of horizontally curved composite beams of concrete slab and I-section steel beam with shear connectors using the analysis system computer program (ANSYS V. 9.0 2004).

A comparison is made between the results obtained from the finite element analysis and the available experimental results. The comparison shows good agreement. The maximum difference in ultimate loads was (13.2%). Parametric study was performed to study the influence of several important parameters on the overall behavior of a horizontally curved composite beam. These parameters include the curvature (L/R) of the beam, supports conditions and concrete compressive strength. L/R has significant influence as more and more twisting effects will be introduced.

Keywords: Steel-concrete composite beam, Beams curved in plan, finite element analysis.

التحليل لحد الفشل للعتبة المركبة المنحنية افقيا والمتكونة من عتبة حديد وبلاطة كونكريتية مع التداخل الجزئي باستعمال عناصر طابوقية وقشرية

الخلاصة

في هذه الدراسه, تم تقصي سلوك العتبات المركبه المنحنيه افقيا والمتكونه من سقوف خرسانيه وعتبات حديديه والحاوية على روابط قص من خلال تحليلها بطريقة العناصر المحددة باستعمال نموذج ثلاثي الأبعاد مع مراعاة السلوك اللاخطي للمواد بالاستفادة من برنامج ANSYS (الاصدار التاسع,2004).

تمت مقارنة النتائج التي تم الحصول عليها من التحليل بواسطة العناصر المحددة مع نتائج عملية متوفرة. بصورة عامة اظهرت نتائج المقارنة حصول توافق جيد, وأكبر فرق في الحمل الأقصى (13.2٪).وقدأختيرت بعض العوامل المهمه لدراسه تأثيرها على سلوك العتبات المركبه المنحنيه.هذه العوامل تتضمن تقوس العتبة,ظروف المساند ومقاومه الانضغاط للخرسانه. أظهرت النتائج أن تقوس العتبة له تأثير كبيرحيث تأثير اللي يزداد بزيادة التقوس.

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1.Introduction

The aim of using or selecting any material in construction is to make full use of its properties in order to get best performance for the structure being constructed keeping in mind the availability, strength, stiffness, workability, durability of the material and economy of construction [1].The properties of each material differ from the properties of another material; thus there is no material that can provide all the structural requirements. Different materials can be arranged in optimum geometric configuration, to make use of the desirable properties of each material. This is known as a composite structure. Thus, the advantageous characteristics of different materials are combined to produce a composite member with high strength, enhanced stiffness, and high carrying capacity.

The term composite construction means usually steel beams or girders attached to concrete slab by means of mechanical connectors Fig(1).

The coupling between the steel beam and the concrete slab offers both economical and structural benefits. Composite construction is used extensively in the construction of modern buildings and highway bridges.

The use of horizontally curved girders has increased considerably in recent years for highway bridges and interchanges in large urban areas. Using continuous curved girders also permits the use of shallower sections as well as a reduction in the slab overhang of outside girders. The continuous curved girder also provides a more esthetically pleasing structure with its streamlined appearance [2]. A horizontally curved girder subjected to gravity loads (load perpendicular to the plan of curvature), Fig.(2), not only undergoes a vertical displacement, but twists with respect to its longitudinal axis.

2. Literature Review

Tests on composite straight beams had been carried out in the early 1920's [3]. A composite beam consists of two components of different materials (usually structural steel beam and cast in-situ concrete slab) connected together by means of shear connectors at the interface, whereby partial or complete interaction between the two components takes place.

Johnson and May [4], in 1975, described situations in which, it is advantageous to use composite steel-concrete beams with fewer shear connectors than the number required for full interaction. From the study of the results of tests and computation, simple rules were derived for estimating the ultimate flexural strength of such beams, and for checking deflections at service load.

The behavior of simply supported composite beams of any construction materials taking into consideration linear and nonlinear behavior of shear connectors was investigated by ***Abdul Razak*** [5] in 1997. The effect of using different spacing of shear connectors along the beam and variation of section geometry on the structural behavior of composite beams were explored. The basic differential equations were written in finite differences and the resulting sets of equations were solved to obtain the slip and the deflection at any point in the beam.

In 2000, ***Chen et al.*** [6] tested five beams of full scale dimensions built from steel beams and concrete slabs to failure. Each of the beams was simply supported at the ends and was subjected to a concentrated load applied at mid–span. They also examined the effects of curvature on the ultimate strength of such beams. The test results indicated that the load-carrying capacity decreases with the increase in the ratio of span/radius of curvature. The main cause of failure changes from bending to the combined action of bending and twisting.

Gorgis [7], in 2006, developed a nonlinear horizontally curved composite one-dimensional finite element model based on displacement method for the analysis of horizontally curved composite beams of concrete slab and steel beams. The composite curved beam element was based on the partial interaction theory where the flexibility of shear connectors was allowed.

3. Materials Idealization

- SOLD65 Element Description

This 8-node isoparametric linear brick element is used, in this study, to simulate the behavior of concrete slab. Each of the eight corner nodes has three degrees of freedom, displacements u, v and w in x, y and z-directions, respectively [8] , Fig.(3) .

- Reinforcement Idealization

In the present research work, the reinforcement is included within the properties of the 8-node brick elements (embedded representation) to account for the reinforcement effect in the concrete structures. The bar elements are assumed to be built into the brick elements. In this approach perfect bond is assumed between the reinforcing bars and the surrounding concrete , Fig.(4) .

- SHELL63 Element Description

Three-dimensional 4-node shell element is used to simulate the behavior of the steel beam. Each node has five degrees of freedom, translations in the nodal in x, y and z-direction and rotation in the nodal in x and y-direction, Fig.(5) .

- LINK8 Element Description

This element is used to simulate the behavior of shear connectors to transfer normal force between the concrete and the steel beam and to resist the uplift separation,Fig.(6).

- COMBIN39 Element Description

This element is used to simulate the behavior of the shear connectors in resisting the horizontal shear between the concrete and the steel beam and to resist the slip,Fig.(7).

- Shear Friction and Contact Modeling

A three-dimensional nonlinear surface-to-surface "contact-pair" element was used to model the nonlinear behavior of the contact surface between the concrete and the steel beam. The contact-pair consists of two boundaries, (CONTACT 173) and (TARGET 170). The contact element is capable of supporting compression in the direction normal to the interface between the two surfaces and Coulomb shear friction in the tangential direction ,Fig.(8).

4. Materials Properties

- Modeling of concrete

The concrete is assumed to be homogeneous and initially isotropic. The stress-strain relations are described by an elastic-perfectly plastic brittle fracture model, Fig.(9) .

- Modeling of Cracked Concrete

The cracking of concrete is modeled as "a smeared-cracking model". In this approach, it is assumed that the concrete becomes orthotropic after the first cracking has occurred with eventually zero modulus of elasticity in the direction normal to the crack [9], Fig.(10).

- 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 strain-stress curve is the elastic- perfectly plastic relation which ignores the strain hardening region as shown in Fig.(11)[10].

- Modeling of shear connectors

When structural members deform under external vertical loads, large horizontal (shearing) forces are developed that act on the planes of contact region. Shear forces may be transferred by means of friction and by the dowel action of the shear connectors, where the main function of shear connectors is to transmit longitudinal shear between the concrete slab and the steel beam. They also have the function of keeping the two materials stuck together against uplift, (i.e.) against the separation of the two materials. The normal forces transmitted by the axial forces in the shear connectors are modeled by using a link element (LINK8). While, the shear forces that are transmitted by shearing and flexure of the shear connectors are modeled by using a nonlinear spring element (COMBIN39).Millard and Johnson [11] dowel formula is used to resist slip between concrete and steel components.

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

F_{du} = Ultimate dowel force, given by:

$$1.3\phi^2\sqrt{1.2\ f'_c\ f_y}\ F_{du} =$$

k_i, is the initial dowel stiffness ,

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

G_f, foundation modulus of concrete and it is taken as 750 N/mm^3 for 1.2 $f'_c \leq 35$ Mpa ,and

$\sqrt{1.2\ f'_c}$ proportional to for 1.2 $f'_c > 35$ MPa

ϕ , is the stud diameter.

E_s, elastic modulus of steel stud.

5. Numerical Application

In order to verify that the analysis by the finite element method using ANSYS program is applicable to curved in plan composite steel-concrete beams, a series of tests on simply supported curved in plan composite beams having different ratio of span/radius of curvature were done by Chen et al.[6]. The same beams were analyzed theoretically by Gorgis[7] by using a horizontally curved beam element, in which L/R ranges form .1 to 0.5. Three beams of realistic dimensions built from steel beams and concrete slabs were tested to failure. Details of these beams are given in table (1-a) and fig. (12), and the material properties of concrete and steel are given in table (1-b), where :

B = Concrete slab width.
Ds = Concrete slab thickness.
b = Flange width of steel beam.
D = Height of steel beam.
t_f = Flange thickness of steel beam.
t_w = Web thickness of steel beam.
L_s = Total length of beam.
L = Clear length of beam .
R = radius of curvature .
fc' = compressive strength of concrete,
fy = yield stress of reinforcement,
Fy* = yield stress of steel beams.

In general good agreement is obtained between the present finite element and the experimental results. The maximum difference in ultimate loads was (13.2%) ,table (2) and Fig.(13).

6. Parametric Study

The behavior of a horizontally curved composite beam is affected by many parameters. In the current study the beam (SP1) has been chosen in a numerical study to demonstrate the effects of some parameters on the nonlinear finite element solution. These parameters include the following:

- The effect of curvature (L/R) of the beam.
- Effect of supports conditions.
- Effect of compressive strength of concrete.

v <u>Effect of Curvature (L/R) of the Beam</u>

- A decrease in L/R ratio from 0.1 to 0.05 causes an increase in ultimate load about (11.5%).
- An increase in L/R ratio from 0.1 to 0.2 causes a decrease in ultimate load about (11.2%).

Fig.(14) shows the load-deflection curves for various L/R ratios .

v <u>Effect of Supports Conditions</u>

- If the ends of the beam have been fixed (fixed end beam), the ultimate load is increased by (48.1 %) with respect to the beam with simple supports at ends.
- When one end is fixed and roller at the other end (fixed-roller beam), the ultimate load is increased by (6 %) with respect to the hinge-roller case.

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

v <u>Effect of Compressive Strength of Concrete on Ultimate Load</u>

- If the compressive strength increases by (25%) (from the value 28.6 MPa to 35.75 MPa), the ultimate load is increased by about (18%) (from 445 kN to 525 kN)in the beam
- If the compressive strength decreases by (25%) (from the value of 28.6 MPa to 21.45 MPa), the ultimate load is reduced by about (4%) (from 445 kN to 430 kN)in the beam.

Fig.(16) shows the effect of $f'c$ on the load-deflection curve.

- Effect of Compressive Strength of Concrete on Load-Slip Behavior

- If the compressive strength increases by (25%), a decrease occurs in end slip of beam SP1 by (11.6%) (for the same load level 400 kN).
- If the compressive strength decreases by (25%), an increase occurs in end slip of beam SP1 by (24%) (for the same load level).

Fig.(16) shows the effect of $f'c$ on the load-end slip curve.

7. Conclusions

Based on the results of the available experimental tests used for assessing the results obtained from the present finite element analysis by (ANSYS), it is 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 0.5 the main cause of failure changes from 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 beam simply supported at two ends.
- When the compressive strength increases the ultimate load increases and the amount of maximum slip between concrete slab and steel beam (at ends) decreases, while when the compressive strength decreases the ultimate load will decrease but the amount of maximum slip (at ends) increases.

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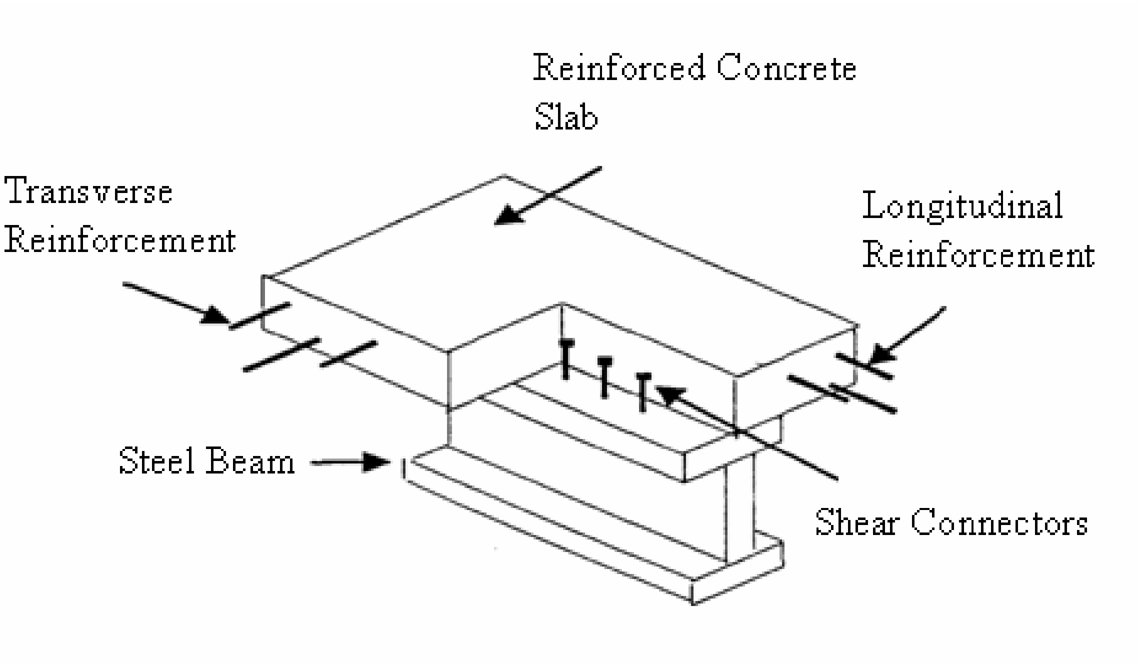
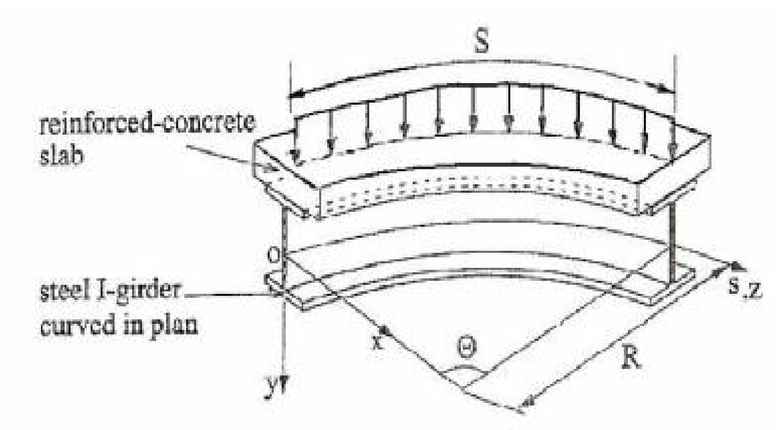
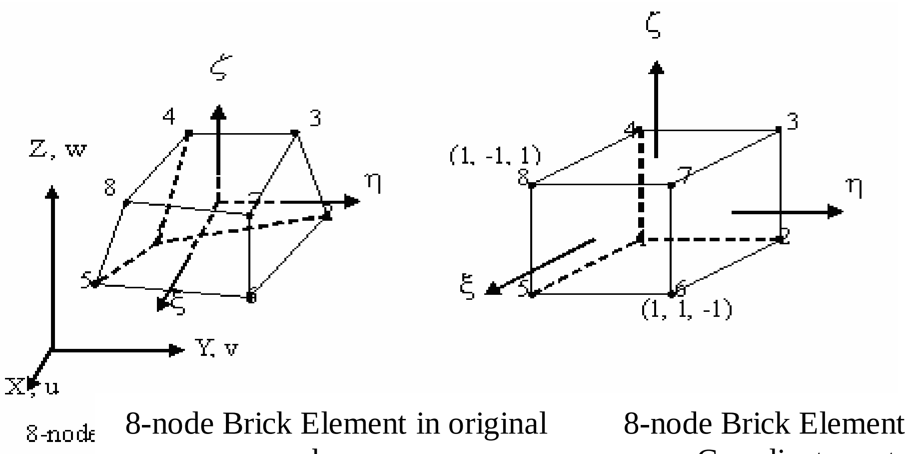


Figure (1) Composite beam components



S = Arc length
R = Radius

Figure (2) Composite steel and concrete beam curved in plan.



8-node Brick Element in original shape

8-node Brick Element in local Coordinate system

Figure (3) Brick element with 8 nodes (Solid 65 in ANSYS)[(8)].

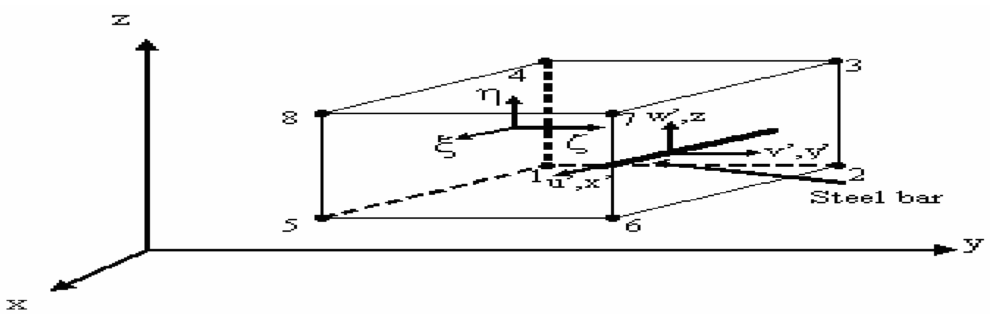
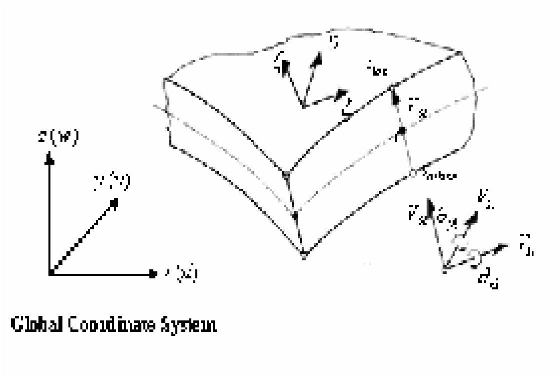


Figure (4) Embedded steel bar representation.



Figure(5) Shell element (Shell 63 in ANSYS)[8].

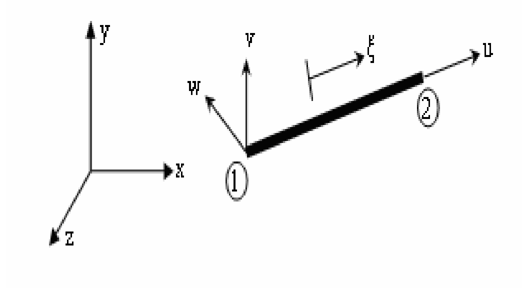


Figure (6) Bar element (Link 8 in ANSYS)[8] .

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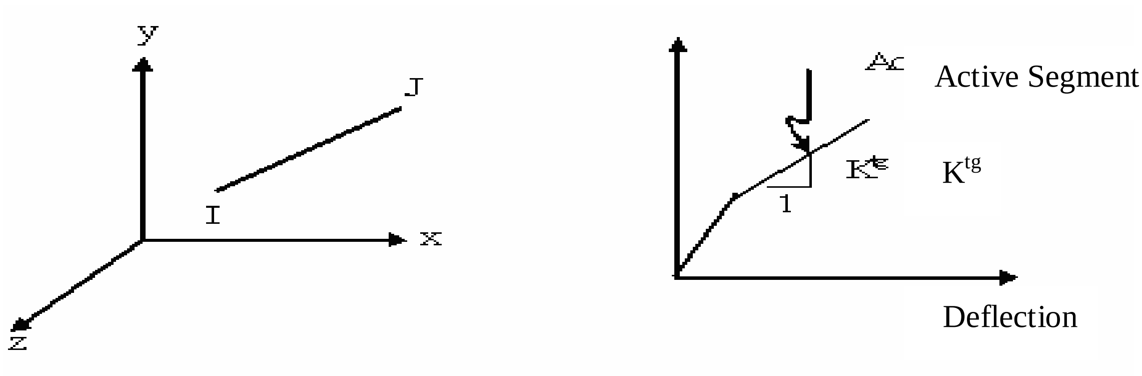


Figure (7) Nonlinear spring element (Combine 39 in ANSYS) [8] .

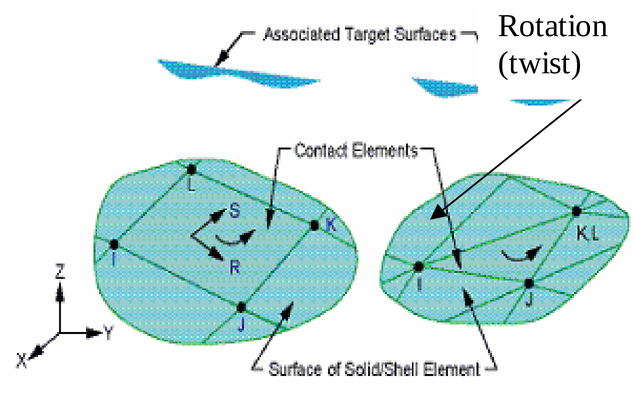
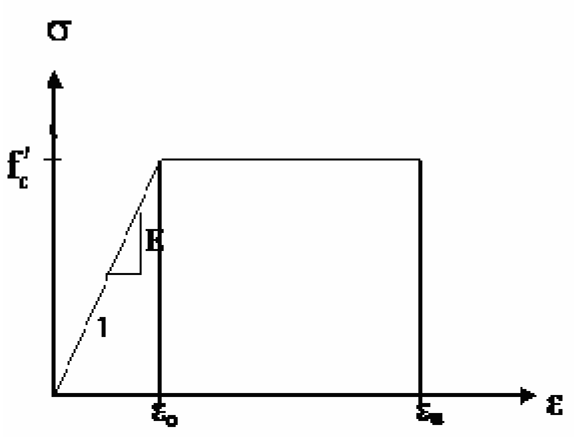


Figure (8) Geometry of CONTACT 173[8] .



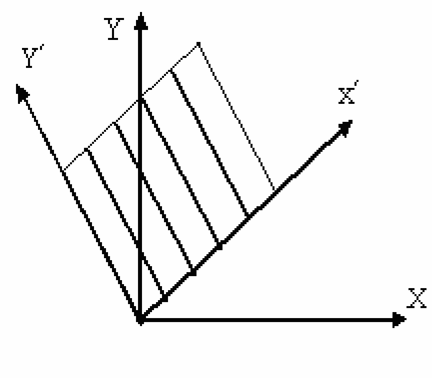


Figure (9) Uniaxial stress-strain relationship used for concrete[8] .

Figure (10) Smeared crack modeling

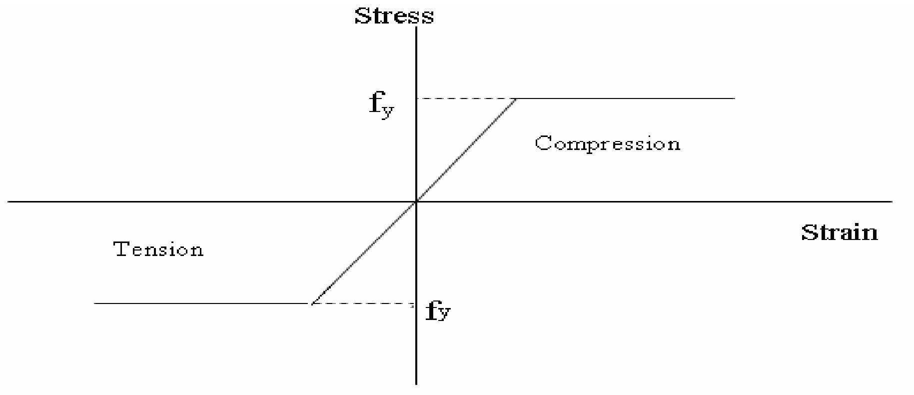


Figure (11) Idealized bilinear stress-strain curve for steel.

Table(1a):

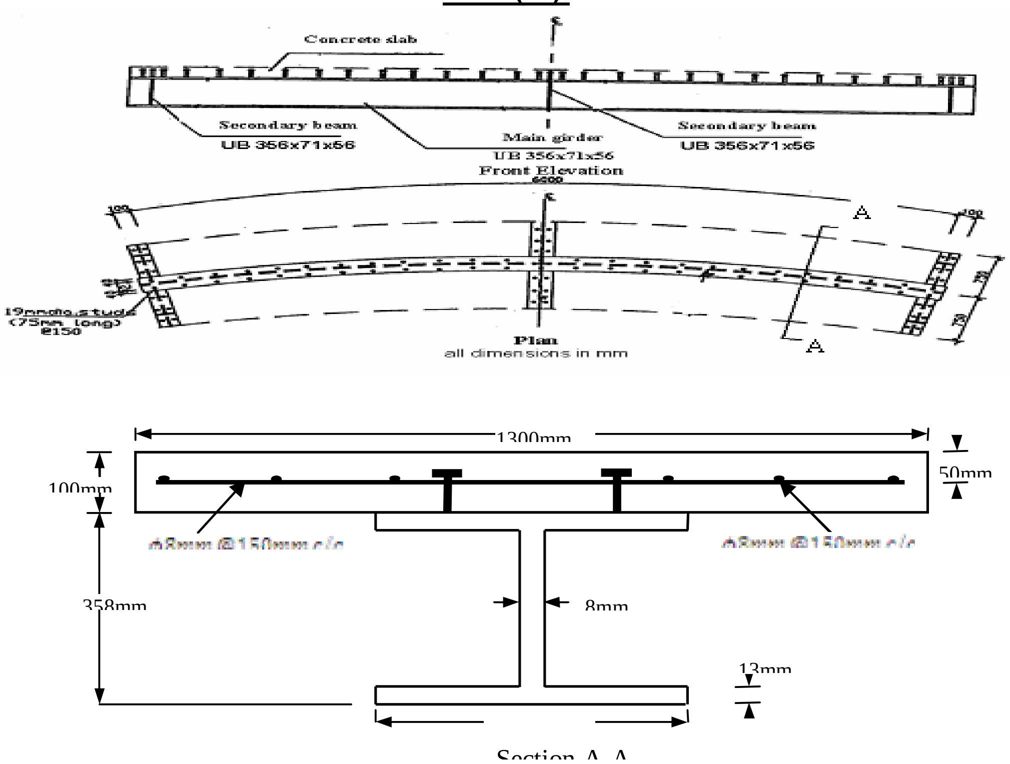
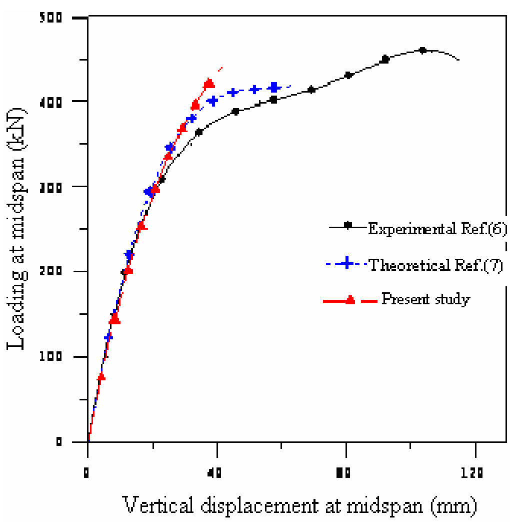
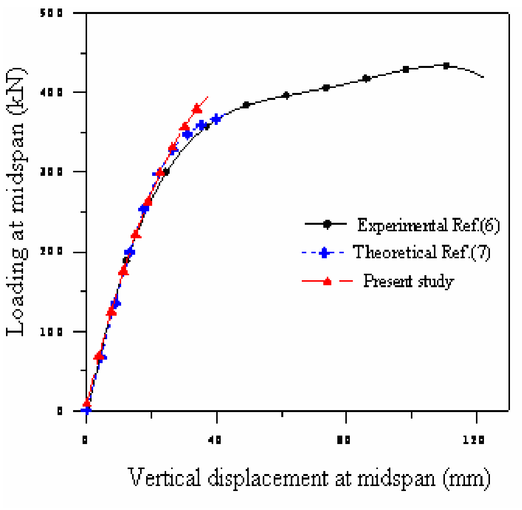


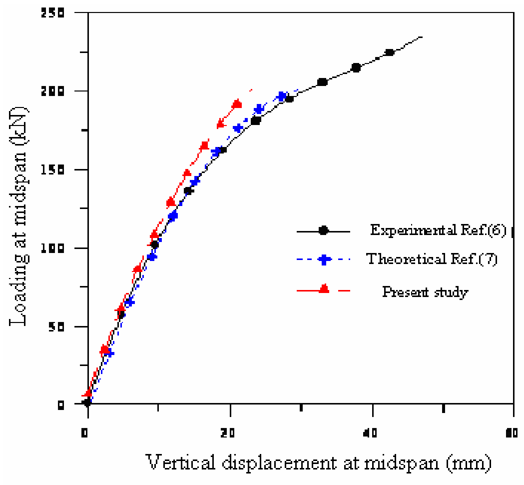
Figure (12) Dimensions and reinforcement details of beams



(a) Beam SP1



(b) Beam SP2



(c) Beam SP3

Figure (13) Load-vertical displacement curves of horizontally curved composite beams

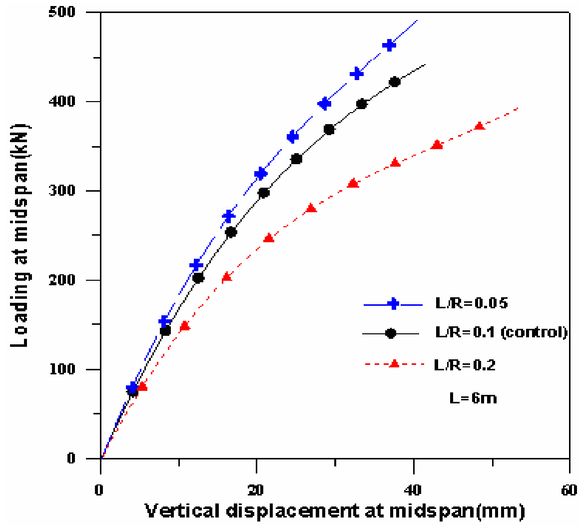


Figure (14) Effect of curvature (L/R) of beam (SP1) on load-vertical displacement curves.

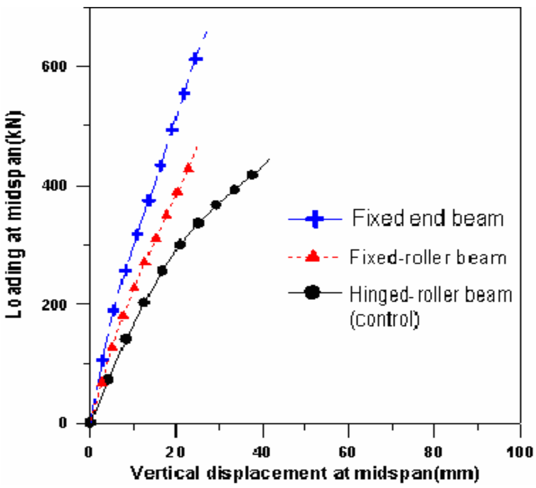
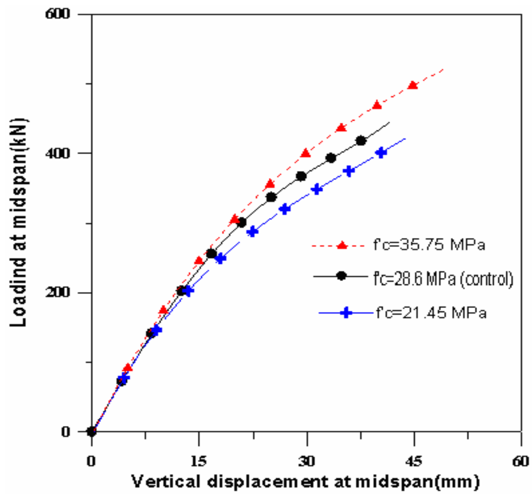


Figure (15) Effect of supports conditions of beam (SP1) on load-vertical displacement curves.



Figure(16) Effect of (f´c) of beam (SP1) on load-vertical displacement curves.

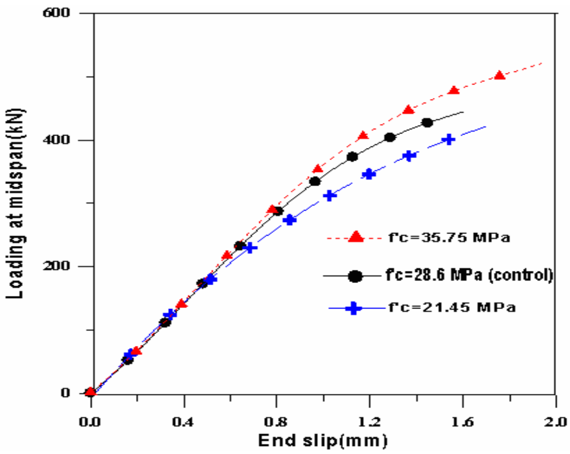


Figure (17) Effect of (f´c) on load-end slip curves for beam SP1.