Investigation of the Behavior for Reinforced Concrete Beam Using Non-Linear Three-Dimensional Finite Elements Model

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Abstract

This study presents theoretical investigation that reinforced concrete and composite construction might be suitably combined to give a new structural material: composite reinforced concrete. To study theoretically the composite beam, nonlinear three-dimensional finite elements have been used to analyze the tested beam.

The 8-node brick elements in (ANSYS) are used to represent the concrete, the steel bars are modeled as discrete axial members connected with concrete elements at shared nodes assuming perfect bond between the concrete and the steel.

The results obtained by finite element solution showed good agreement with experimental results.

Keywords: reinforced concrete, composite construction, finite elements, ANSYS

دراسة تصرف العتبات الخرسانية المسلحة باستخدام العناصر المحددة اللاخطية ثلاثية الابعاد

الخلاصة

تقدم هذة الدراسة بحثا نظريا لسلوك العتبات الخرسانية المركبة المفحوصة مختبريا ، تم استخدام عناصر محددة ثلاثية الابعاد لا خطية في برنامج العناصر المحددة **(ANSYS)**. لتمثيل الا جزاء الخرسانية (الاعتيادية، عالية المقاومة والمسلحة بالياف الحديد) تم استخدام العناصر الطابوقية ذات الثمانية عقد، و لتمثيل قضبان التسليح استخدمت عناصر محورية منفصلة (Discrete axial elements).

اظهرت النتائج بشكل عام حصول توافق جيد بين نتائج العناصر المحدودة مع النتائج المختبرية

الكلمات الرئيسية: الخرسانة المسلحة–المنشأت المركبة–العناصر المحددة–ansys

Literature Review

1. Composite Beams

Many researches studied the behavior of simply supported composite beams. Some of these models, which are comprehensive and worth evaluating, are reviewed herein.

In 1975, Johnson has derived a differential equation for Newmark. The equilibrium and compatibility equations are reduced to a single second order differential equation in terms of interface slip instead of axial forces. The solution of which lead to slip values at the interface along the

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beam span, after satisfying the suitable boundary conditions.

In 1985, Roberts presented an elastic analysis for composite beams with partial interaction assuming a linear shear connector behavior while the normal stiffness of the connectors was taken infinity. The basic equilibrium and compatibility equations were expressed in terms of four independent displacements, which are the horizontal and vertical displacements in each component of the composite section. These equations were solved using finite difference representation of various derivatives.

2.Nonlinear Finite Element (by using ANSYS program)

In 2006 Ali Hameed Aziz has investigated experimentally the strength, deflection and ductility of reinforced concrete I-beams made of normal or hybrid reinforced concrete under two point monotonic loads. The experimental work includes the following four main categories:

i- Flexural behavior of I-beams cast monolithically.

ii- Flexural behavior of I-beams cast in two-step procedure (with one construction joint).

iii- Flexural behavior of I-beams cast in three-step procedure (with two construction joints).

iv- Shear behavior of I-beams cast monolithically, but, the web is made with concrete different from the concrete of compression and tension flanges.

To implement a nonlinear finite element procedure to analyze all tested beams.

Introduction

The idea for a new form of construction emerged from two separate research investigations. One of these on composite construction with deep haunches, the other was on the use of very high strength steels in reinforced concrete. Both these separate modes of construction, although as yet little used in practice, will undoubtedly develop further in their own right. However, they have some disadvantages 2which will mitigate against their development, but by altering slightly the form of the deep haunch, the disadvantages of both can be largely overcome. The resulting form of construction is known as composite reinforced concrete.

The normal form of composite construction is shown in Fig.1. The main advantage of using deep haunches as in Fig.2 is the considerable economy that can be affected in the amount of steelwork. This can be 40% of that used in normal composite construction, even for the same overall depth. The deep haunch can be formed easily by precast units or similar spanning between the steel beams and the problem of deep haunches composite beams developed form the desirability to use this method of construction.

Ansys Computer Program

In the present study, the ANSYS program of version (9.0) was employed for analyzing all tested beams as well as the finite element modeling for concrete, steel reinforcement.

ANSYS (**AN**alysis **SYS**tem) is a comprehensive general-purpose finite element computer program that contains over 100,000 lines of code and more than (180) different elements. It is capable of performing static, dynamic, heat transfer, fluid flow, and electromagnetism analysis. It can be used in many engineering fields, including structures, aerospace, electronic and nuclear problems. In 1971, the earliest version of ANSYS program was released for the first time.

One of the main advantages of ANSYS is the integration of the three phases of finite element analysis: pre-processing, solution and post-processing.

Pre-processing routines in ANSYS define the model, boundary conditions, and loadings. Displays may be created interactively on a graphics terminal as the data are input to assist the model verification. Post-processing routines may be used to retrieve analysis results in a variety of ways. Plots of the structure's deformed shape and stress or strain contours can be obtained in the post-processing stage.

Equilibrium Conditions

The equilibrium equation for a nonlinear structure in a static equilibrium is derived using the principle of virtual work. The principle states that " if a general structure in equilibrium is subjected to a system of small virtual displacements within a compatible state of deformation, the virtual work due to the external action is equal to the virtual strain energy due to the internal stress"(67); Thus:

$$W_{int}=W_{ext} \qquad \text{……….} \ (5\text{-}1)$$

where

$W_{int.}$ = internal work (strain energy)

$W_{ext.}$ = external work (work done by the applied force)

The virtual internal work is:

$$W_{int.} = \int_{v} \{\partial\varepsilon\}^{T} \{\sigma\}.dV \qquad \text{……..} \ (5\text{-}2)$$

where:

$\{\varepsilon\}$ = elements of virtual strain vector

$\{\sigma\}$ = elements of real stress vector

dV = infinitesimal volume of the element

By using the general stress-strain relationship, stresses $\{\sigma\}$, can be determined from the corresponding strains $\{\varepsilon\}$ as:

$$\{\sigma\}=[D]\cdot\{\varepsilon\} \qquad \text{…………} \ (5\text{-}3)$$

where

$[D]$ =constitutive matrix

After substituting Equation (5-3) into (5-2), the virtual internal work can be written as:

$$W_{int.} = \int_{v} \{\partial\varepsilon\}^T [D] \{\varepsilon\} \, dV \quad \cdots (5\text{-}4)$$

The displacements {U} within the element are related by interpolation to nodal displacements {a} by:

$$\{U\}=[N]\cdot\{a\} \quad \text{.……... (5-5)}$$

where

$[N]$ = shape function matrix

{a} =unknown nodal displacements vector (local displacements)

{U}= body displacements vector (global displacements).

By differentiating Equation (5-5), the strains for an element can be related to its nodal displacements by:

$$\{\varepsilon\} = [B] \{a\} \quad \text{…….(5-6)}$$

where

$[B]$= strain-nodal displacement relation matrix, based on the element shape functions

Assuming that all effects are in the global Cartesian system, and then combining Equation (5-6) with Equation (5-4) yields:

$$W_{int.} = \{\partial a\}^T . \int_{v} [B]^T [D] [B] \, dV \, .\{a\} \quad \text{..… (5-7)}$$

The external work, which is caused by the nodal forces applied to the element, can be accounted for by:

$$W_{ext.}=\{a\}^T\cdot\{F\} \quad \text{……..… (5-8)}$$

where

{F}= nodal forces applied to the element

Finally, Equations (5.1), (5.7) and (5.8) may be combined to give:

$$\{\partial a\}^T \int_{v} [B]^T [D] [B] \, dV \{a\} = \{\partial a\}^T \{F\} \quad \text{..……... (5-9)}$$

Noting that $\{\partial a\}^T$ vector is a set of arbitrary virtual displacements, the condition required to satisfy Equation (5-9) can be reduced to:

$$[K^e]\cdot\{a\}=\{F\} \quad \text{……… (5-10)}$$

where

$$[K^e] = \int_{v} [B]^T [D] [B] \, dV \quad \text{. …….. (5-11)}$$

[K^e] = Element stiffness matrix

dV = dx . dy . dz

Equation (5-10) represents the equilibrium equation on a one-element basis. For all elements, the overall stiffness matrix of the structure $[K]$ is built up by adding the element stiffness matrices (adding one element at a time), after transforming from the local to the (overall) global coordinates, this equation can be written as:

$$[K] \{a\} = \{F^a\} \quad \text{……… (5-12)}$$

where

$[K] = \sum_{n} [K^e]$= overall structural stiffness matrix

$\{F^a\} = \{F\}$= vector of applied loads (total external force vector)

n = total number of elements

Finite Element Representation

As mentioned before, the **ANSYS** computer program was utilized for analyzing all tested beams. Structural components encountered throughout the current study, corresponding finite element representation and corresponding elements designation in **ANSYS** are presented in Table (1).

1-Finite Element Model of Concrete

The finite element idealization of normal, high and steel fiber reinforced concrete members should be able to represent the concrete cracking, crushing, the interaction between concrete and reinforcement, the interaction between concrete and steel fibers to reduce crack growth and the capability of concrete to transfer shear after cracking by aggregate interlock.

In order to investigate failures where shear plays a major rule, three dimensional elements are to be used . In the current study, three-dimensional brick element with 8 nodes was used to model the concrete (SOLID-65 in ANSYS). The element has eight corner nodes, and each node has three degrees of freedom (u, v and w in x, y and z direction respectively). The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The geometry and node locations for this element type are shown in Fig.(3).

2-Finite Element Model of Reinforcement

Three techniques were existing to model steel reinforcement in finite element models for reinforced concrete[(69)], these are:-

2-1 Discrete Representation

2-2 Embedded Representation

2-3 Smeared (Distributed) Representation

In the present study, the steel reinforcements (tensile, compressive, stirrups and dowel bars) were represented by using 2-node discrete representation (LINK-8 in ANSYS) and included within the properties of 8-node brick elements. 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. To provide the perfect bond**,** the link element for the steel reinforcing bar was connected between nodes of each adjacent concrete solid element, so the two materials share the same nodes.

Modeling of Material Properties

1-Stress-Strain Relationship Model for Concrete

In this study, the concrete is assumed to be homogeneous and initially isotropic. For reinforced concrete, the adopted stress-strain relation is based on work done by Desayi and Krishnan; as shown in Fig (5).

2- Modeling of Reinforcing Bars

Since the reinforcing bars are normally long and relatively slender, they can generally be assumed to be capable of transmitting axial forces only. For the finite element models, the uniaxial stress-strain relation for steel was idealized as a bilinear curve, representing elastic-plastic behavior with strain hardening. This relation is assumed to be identical in tension and in compression as shown in Fig.(6).

Illustrative example

To illustrate the application of the theory presented herein, the example which is presented and tested by R. Taylor and P. Burdon was used to carry out a convergence study and to examine the effect of some properties on the behavior of a composite beam Fig.(7). The beam was 15 ft long. Used 6 in x 3 in channel. The beam was simply supported over a span of 14 ft 8 in. and subject to two equal concentrated loads at 12 in. either side mid span. Load was applied in increments up to collapse of the beam. After the increments measurements were made of deflection, crack widths and strains in the steel channel and the compression zone of concrete. Stirrup reinforcement in the webs of the beams was provided to prevent failure by diagonal cracking. The longitudinal shear at the interface of the concrete and channel. For the 6 in. x 3 in. channel the studs were 5/8 in. dia. By 3 in. high. The spacing of studs was 6 in. Test on steel specimen cut from the steel channel gave average yield stresses of 46000 lb/sq.in.

Meshing

After creating of volumes, a finite element analysis requires meshing of the model. In other wards, the model is divided into a number of small elements, and after loading, stresses and strains are calculated at integration points of these small elements. To obtain good results, the mesh was set up such that square or rectangular elements were created, Fig. (8).

Analysis of beam

In order to analyze the specimen, the deflections (Vertical displacements) were measured at mid-span at the center of the web of the beam, in y-direction (U_y). Deflected shape of finite element control beam due to the vertical load is shown in Figure The load versus deflection curve obtained from the numerical study together with the experimental curve are presented and compared in Fig.(10). In general, it can be noted from the load-deflection curve that the finite element analyses is agree well with the experimental result throughout the entire range of behavior.

When comparing with the experimental values, all the numerical models show large deflection at the ultimate stage.

Behavior of beam under load

Cracking became visible on the sides of the beam at 18-27% of the ultimate load. This early cracking consisted of several fine short vertical cracks in the central constant moment region of the beam.

As the load increased the cracks extended up the web and additional cracking occurred outside the load points. This additional cracking extended in an inclined direction as is usual in a region of shear. A summary of the maximum flexural crack widths is given in Fig.(12).

The Effect of Type of Applied Load

In order to inspect the effect of type of applied load on the behavior of a composite beam, a numerical study has been carried out, one with concentrated point load (Pc) , and the other with uniform load (Pu) . It can be observed form Fig. (13) that the response of the specimen at Pc is softer than the response of the specimen at Pu.

Failure

The maximum load of beam was reached when the concrete in the flange of the beam between the load points crushed. The result of flexural cracks becoming very wide and extending up the beam.

Conclusions

The Main conclusion to be drawn from this investigation is that composite reinforced concrete is a viable structural form. Flexural cracks up to the working load stage remain very fine and the calculation of their width is unlikely to be necessary in design. The arrangement of reinforcement and steel channel is ideally suited for the use of very high strength reinforcing steels, and reinforcement stresses over 120000 lb/sq. can be used at the ultimate load while still satisfying the serviceability requirements at working load. There are no cracks at the bottom of the beam because of the channel. There will be cracks in the concrete web, but these should remain fine, and they will not be visible.

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Table (1) Finite Element Representation of Structural Components

Structural Component	**Finite Element Representation**	**Element Designation in ANSYS**
Concrete	8-node Brick Element (3 Translation DOF per node)	SOLID 65
Reinforcement (Tensile Steel, Compressive Steel, Stirrups, Studs)	2-node Discrete Element (3 Translation DOF per node)	3D-SPAR 8 (LINK-8)
Steel Plates	8-node Brick Element (3 Translation DOF per node)	Solid 45

Table (2) Details of beam

Reinforce-ment	28 day concrete Strength, lb/sq. in.	Theoretical stress in reinforcement at collapse, lb/sq.in.x10	Experimental Collapse load, tons	Max. stress in channel,lb/sq.in.x10
Two 1/4 in. Mild	6360	41	24.6	27.9

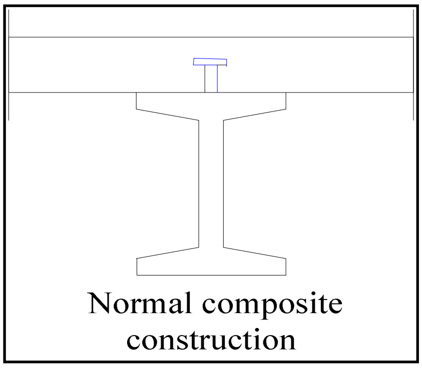
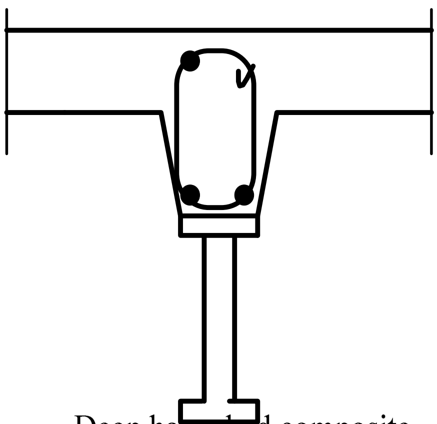
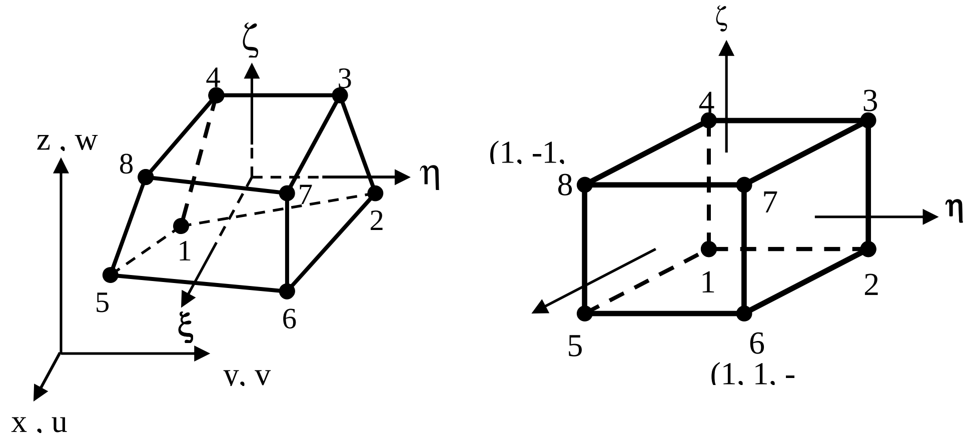


Figure (1)



Deep haunched composite construction

Figure (2)



a) General 8-node Brick Element

b) 8-node Brick Element in Local Coordinate System

Figure (3) Three Dimensional 8-node Brick Element

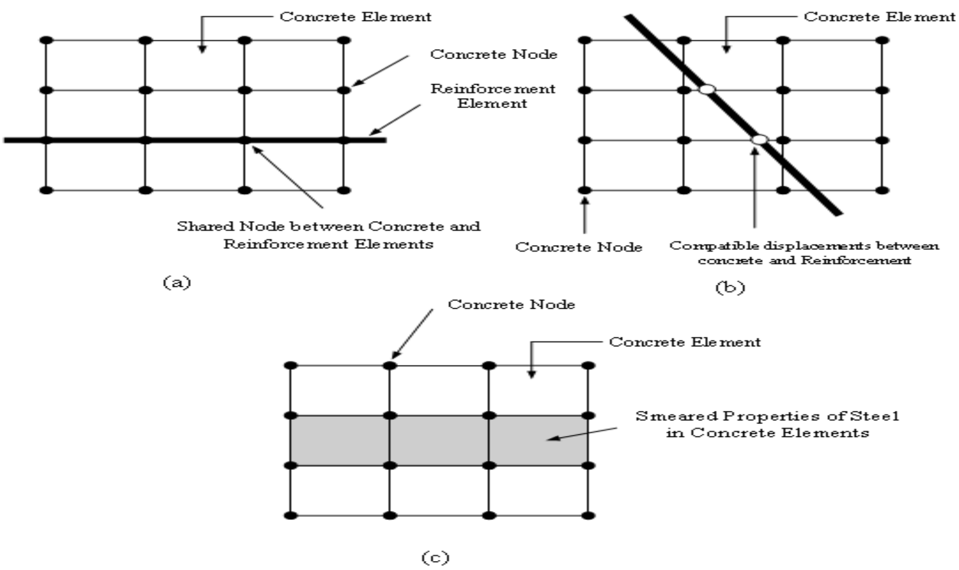


Figure (4) Models for Reinforcement in Reinforced Concrete[69] :
(a) Discrete; (b) Embedded; and (c) Smeared

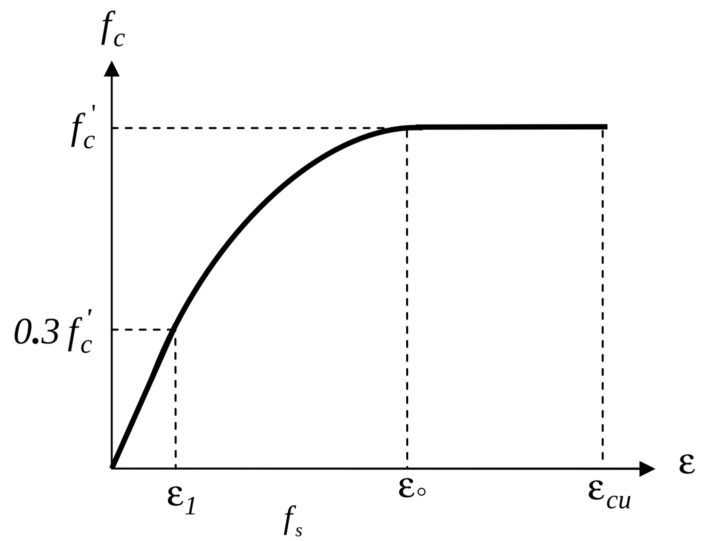


Figure (5) Stress-Strain Relationship Model

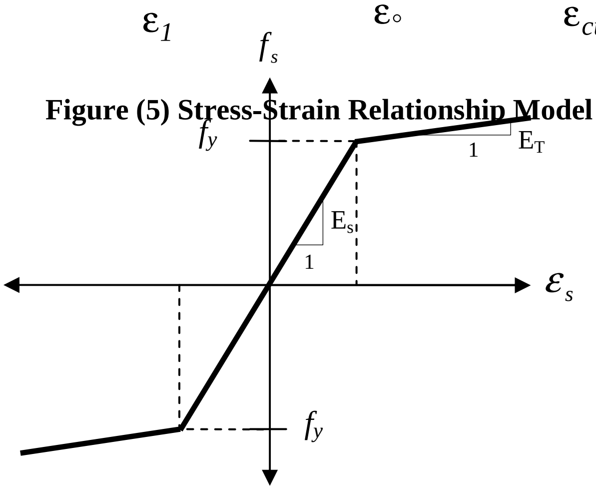


Figure (6) Modeling of Reinforcing bars

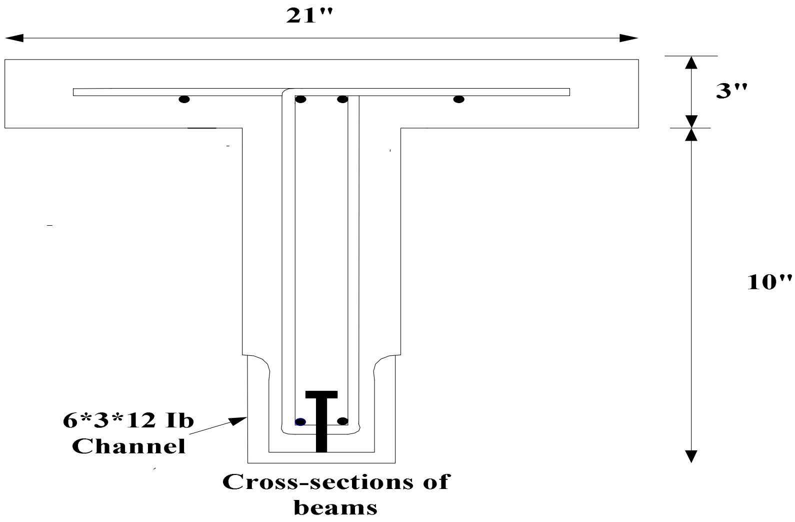


Figure (7)Cross-sections of beam

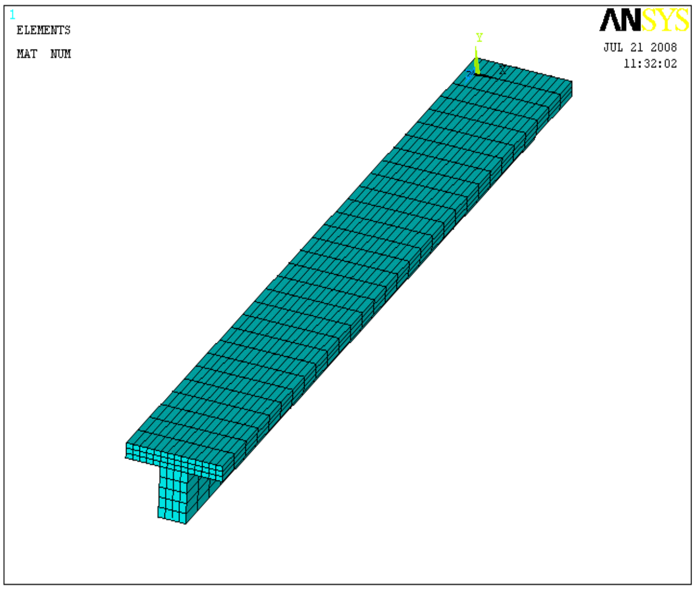


Figure (8) the mesh

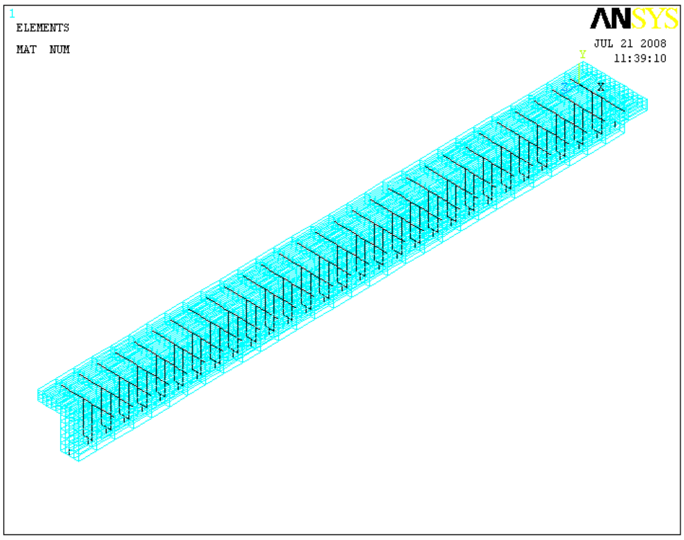


Figure (9)the mesh of reinforcement

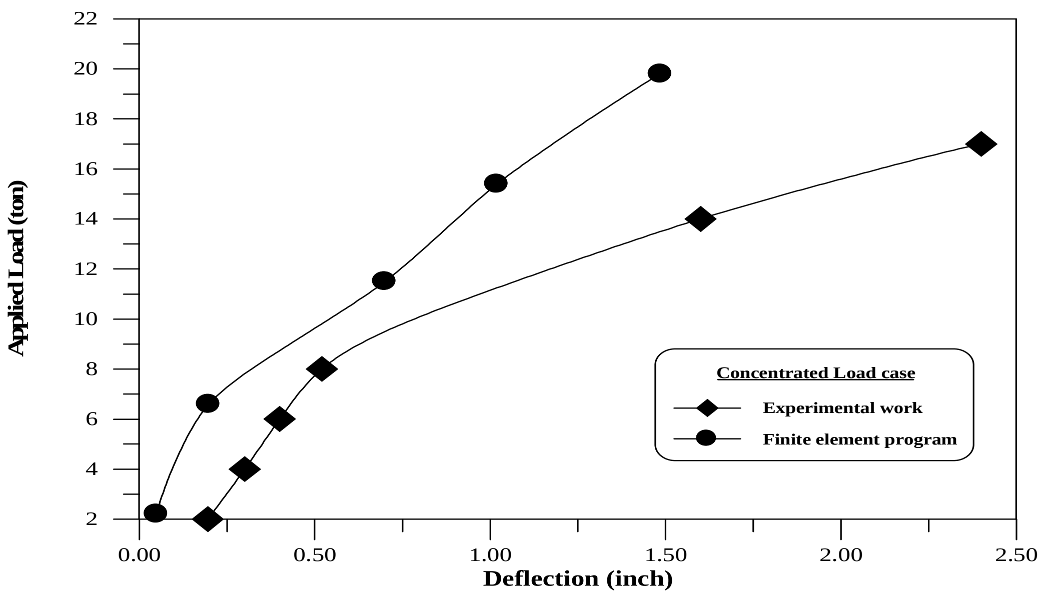


Figure (10) Load-Deflection curve

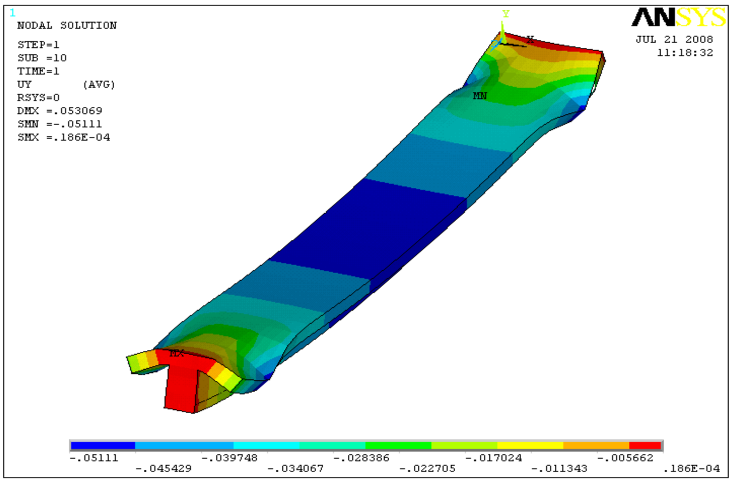


Figure (11) Deflection at the ultimate stage for concentrated point load

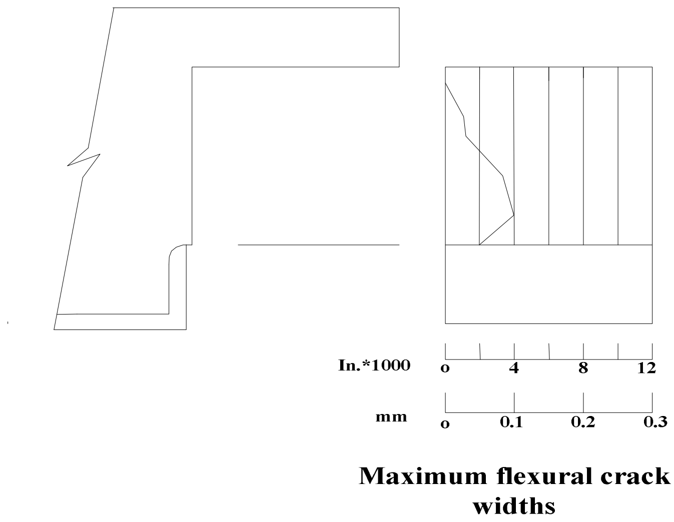


Figure (12) Max. Flexural crack widths

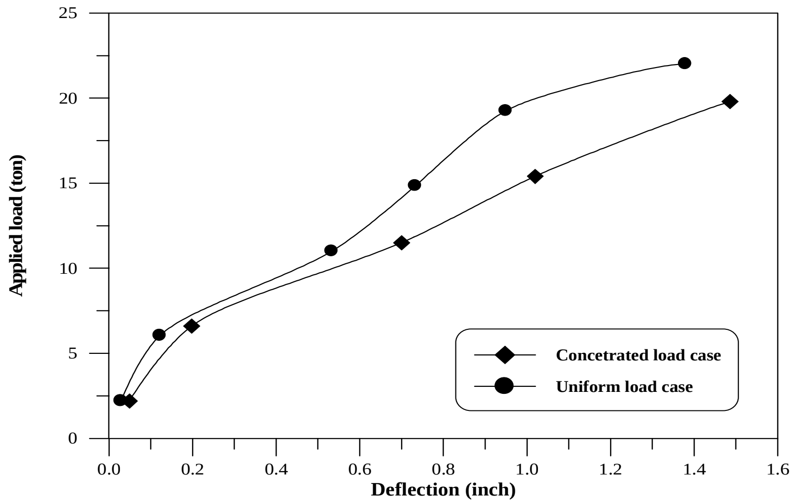


Figure (13) Load-Deflection curve

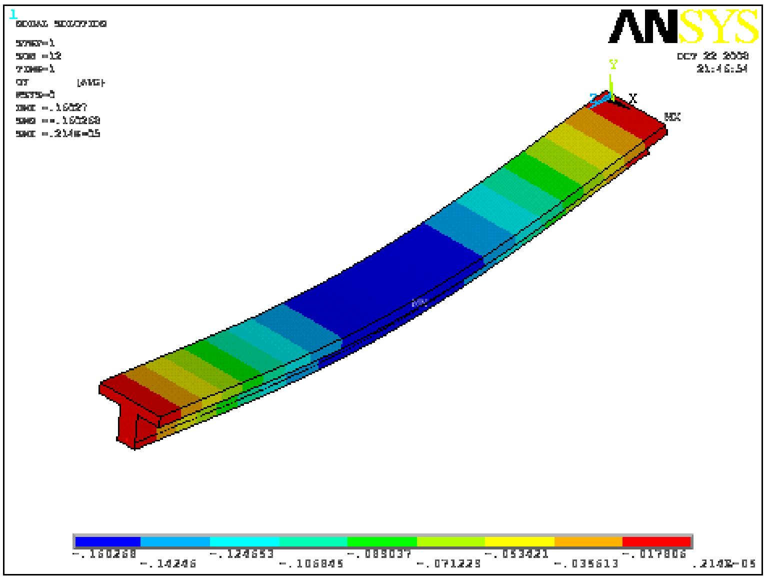


Figure (14) Deflection at the ultimate stage for uniform load