Effect Of Concrete Strength On The Flexural Behavior Of Vierendeel Steel And Concrete Composite Beams

Hayder T. Nimnim, Mohammed Q. Shaaban

Abstract: The scope of this experimental and numerical works is to investigate and study the effect of concrete compressive strength on flexural behavior of composite vierendeel steel-conncrete composite beams when considering the top chord member of the truss (compressive elements) is the concrete slab. The works consist of manufacturing and testing three specimens of 2000 mm span with slab width 1000 mm and each specimen contains two truss. The control beam has 25 MPa compressive strength and other beams have (35, 50) MPa. The results that attained from this study are load-deflection curves, ultimate load capacities, strains, crack patterns and failure modes. The concludes from this study are; an increase concrete strength (f'c) of slab from 25 MPa to 35 MPa leads to increase ultimate load capacity by (28.89) %. Whereas increasing concrete strength from 25 MPa to 50 MPa leads to increase ultimate load capacity by (91.63) %.

Index Terms: Vierendeel truss, Composite truss, Compressive strength, Composite vierendeel beam, Flexural Behavior, Composite steel-concrete beam.

1 INTRODUCTION

Composite trusses with deck steel-concrete slabs systems which combine wide rib profile steel decks support larger spacing and longer spans to be used for designed on an individual basis for a specific job (Brattland and Kennedy 1986) [1]. This provides flexibility in office layout and use. Despite more labors are required demanded per one-tonne of steel for construction, net fabricated steel costs (in comparison to the performance of composite beams) are decreased because of the savings in the weight of steel when the number of trusses in a project is sufficiently great so that standardized fabrication techniques can be developed. Unshared constructions, with the steel deck supporting the wet concrete and the steel trusses supporting themselves and the wet concrete, are rapid and allows other trades to follow closely behind. The open-web system produces a great flexibility for placement of electrical and mechanical services and decreases the distance between ceiling and floor. Composite trusses are very stiff, hence deflections under service conditions are typically small. The intent of this paper is to assist regulatory authorities, engineers, developers, and other interested parties in understanding the effect of concrete compressive strength of simply supported composite vierendeel steel-concrete beams on flexural behavior, and to provide analysis for variable strength on this type of composite truss.

- *Hayder T. Nimnim is currently a doctor of structural engineering in Kufa University, Country-Iraq. E-mail: hayder.alkhazaali@uokufa.edu.iq*
- *Mohammed Q. Shaaban is currently pursuing masters degree program in structural engineering in Kufa University, Country-Iraq. E-mail: mohammedq.shaban@iunajaf.edu.iq moh_eng69@yahoo.com*

2 CHARACTERISTICS AND EXPERIMENTAL PROGRAM OF SPECIMENS

The experimental work consists of three specimens of a composite vierendeel steel-conncrete beams, to find out the flexural behavior. Specimens have a span of 2000 mm and slab width 1000 mm. Concrete slab of all specimens have minimum reinforcement for temperature and shrinkage in long direction which is (Ø8 @ 250 mm) with steel ratio of (ρ=0.18%), while in the short directions the slab was designed according to ACI318M-14 [2] that is the main reinforcement which consisted of (Ø8 @ 115 mm) with steel ratio of (ρ=0.475%) for slab thickness 70 mm as shown in figure (2). The bottom, vertical and diagonal member that makes steel truss with 50 mm in dimension of hollow square section and have thickness 2 mm. The control beam has 70 mm thickness and 25 MPa concrete compressive strength, whilst the other two beams have the same slab thickness 70 mm with f'c 35 MPa and 50 MPa, respectively. All beams were tested under two line loads at the Laboratory of Structure in the Department of Civil Engineering /Faculty of Engineering / University of Kufa. Table (1) shows details of specimens and figure (1) describe sketch of specimens.

Table 1. *Composite Truss Beams Details*

Symbol of Beam	f'c (MPa)	Slab Thickness (mm)	Overall height (mm)	Dimension of opening(mm)	No. of central vierendeel opening
CT1	25	70	385	340 × 265	3
CT2	35	70	385	340 × 265	3
CT3	50	70	385	340 × 265	3

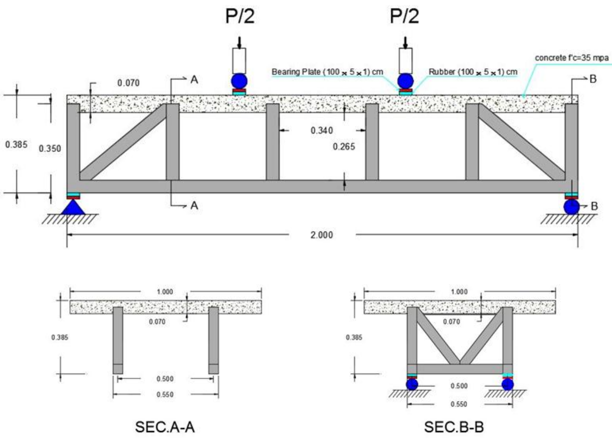


Fig.(1). *Details Of Specimen (m)*

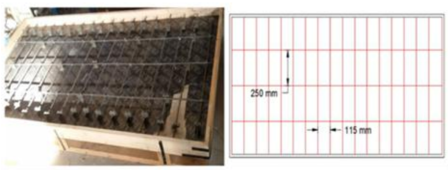


Fig.(2). *Framework and Reinforcement Distribution*

3 MATERIALS PROPERTIES

The properties of all materials, which used to produce the specimens that conclude steel truss and concrete slab, were presented in this section. These materials are: cement, fine and course aggregates, super plasticizer, mixing water, steel truss sections, and steel reinforcement bars.

3.1 Cement

In this study Ordinary Portland cement (Type I) was used. This known commercially (Karsita) which produce from Lafraj Cement Manufacturing Company Taslouja Bazian production (Karbala- Iraq) and conformed to the Iraqi laboratory specifications No. 3868 of the Central Organization for Standardization and Quality Control [3]. The chemical and physical properties of this cement are conformed to the Iraqi specification limits (IQ.S N0.5/1984) [4].

3.2 Fine Aggregate

Normal sand imparted from Al-Najaf zone in Iraq was used as fine aggregate for concrete mixes in this paper. The maximum size of sand has (4.75mm) with soft structure and rounded particle form with fineness modulus of (2.58). Physical and chemical properties and gradient of the sand used was tested according to the Iraqi specification (IQ.S 45/1984) Zone (2) [5] and ASTM C 33/C 33M specification [6].

3.3 Coarse Aggregate

Crushed coarse aggregate was used from (**Maysan city/ chlat quarry**) that content maximum aggregate size 19 mm with specific gravity of (2.68) for casting all concrete slab of specimens. Physical and chemical properties and gradient of the gravel used was tested according to the Iraqi specification (IQ.S 45/1984) [5] and ASTM C 33/C 33M specification [6].

3.4 Super Plasticizer Additives

Super Plasticizer type CF555 is used in this study, which produced By Weber Saint Gobain company and Compatible with: ASTM C 494 – Type D& G [7], BS 5075 Part 1 and BS EN 934, Part 2 [8].

3.5 Mixing Water

In this study ordinary clean tap water was used for concrete mixture as well as washing sand and gravel particles, and curing for all slab specimens.

3.6 Steel Reinforcing Bars

One type of steel reinforcing are used in the present work. For solid concrete slabs, deformed steel bars of size (Ø8 mm) in diameter are used in both directions and conformed to the ASTM A615M specification [9]. The yield and ultimate stresses of reinforcement is 415 and 610 MPa, respectively.

3.7 Steel Truss Section

Hollow square steel section of 50 mm in dimension and have 2 mm thickness, was used in each member that form truss for all tested specimens. Samples from these section was taken according to **ASTM (A 370 – 03a**) [10] and cutted by computer numerical control (CNC) plasma method to find out the yield and ultimate stresses, which are the average value 230.2 and 458.025 MPa, respectively.

4 CONCRETE MIXTURE DESIGN

To reach the optimum proportion of concrete mixing, many trail mix for strength (25, 35, 50) MPa at ages of (7 and 28 days) with Super plasticizer (SP) admixture (CF555) were made depended on ACI 211.1-91, ACI 214 – 02, ACI 318-14 and ACI 211.4R – 93 to achieved an adequate strength and good workability [13] [12] [2] [11]. To obtain high strength concrete (HSC) some consideration are essential to achieve this strength like high cement content, low water/cement ratio and using super plasticizer. The trail mixes were made in the laboratories of the civil engineering department at Kufa University, College of Engineering.

5 TEST SETUP

Three of simply supported composite virendeel steel truss were tested by hydraulic testing machine that have capacity reach to (2000 kN). Two equal line loads were applied at the middle of beams with 650mm distance between loads and 675mm from the support to the line load. The loads are applied every 5 kN for deflection readings, 20 kN for strain readings and 10 KN for tracking cracks pattern which draws on the beam. **Figure (3)** shows details of the tested machine and support with load also.

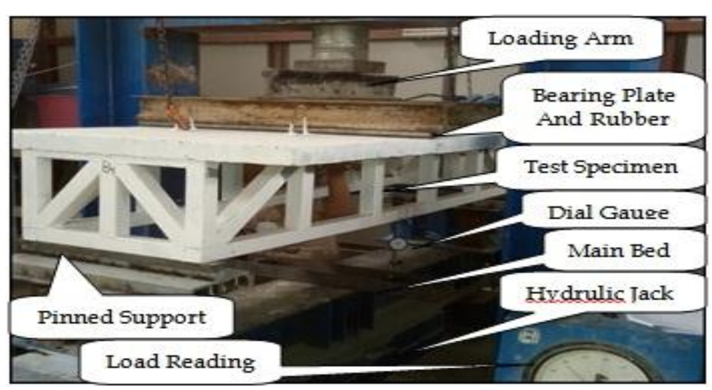


Fig. (3) *Details of The Tested Machine.*

6 EXPERIMENTAL RESULTS

The aim of this section to present the results which can be obtained from specimens prepared to know the effect of concrete compressive strength on the flexural behaviour of this type of beams. The result was studied is the behavior of beams that obtained from modes of failure shape, load-deflection curves at mid-span, strain in the middle section and at the diagonal member, crack pattern, ultimate load and deflection.

6.1 Behavior of Load Deflection

The load-mid span deflection of composite truss beams were measured by using a dial gage at the centre of truss. The different behaviour for all tested beams was taken due to the various formatting of specimens in concrete. So load-deflection curves for all specimens was made by three stages; the elastic stage where linear response was presented, elastic-plastic stage after first cracking and plastic stage where nonlinear response noted Also, this stage included failure. Figure (4) represents a comparison of the load-deflection curve for all specimens. It has been observed that the flexural stiffness and slope of the curve for concrete strength 50 MPa larger than the curves of other strength. While 35 and 25 MPa strength have more ductile in behavior of load-deflection curves.

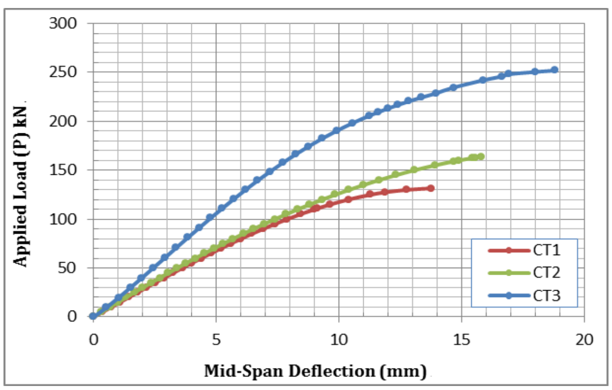


Fig. (4) *Load –Deflection relationships for composite beams.*

6.2 Ultimate Load Capacity of Composite Truss Beams

In this section, will present results and comparisons between all specimens of composite truss beams with respect to control beam for ultimate load. The results of ultimate deflection and load capacity with percentage to the control beam are shown in Table (2). Figure (5) shows the effect of concrete strength on ultimate load.

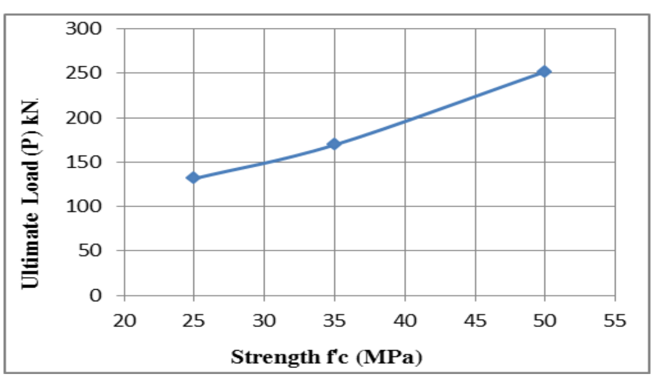


Fig. (5) *Ultimate Load Various According To Concrete Compressive Strength.*

6.3 Cracking Behavior

To assess the behavior of the composite truss beams, crack formation was monitored throughout testing in comparison with the action of control beam. The first cracking loads and cracking pattern of all beams are given in the following sections.

6.3.1 First Cracking Loads

The first cracking load results gained from the tests are presented in Table (2). Figures (6) and (7) displays the ultimate load capacity and load at the first crack with deflection for all specimens, and the percent of load at first crack to ultimate load with deflection, respectively. While the figure (8) shows the ratio of first cracking and ultimate load of various compressive strengths in relation to the control beam (CT1).

Symbol of Beam	Pcr (kN) First crack load	Pu (kN) Ultimate load	% Pcr/Pu	Mid-Span Deflection (mm) At First crack load	Mid-Span Deflection (mm) At Ultimate load	% Δ_{cr}/Δ_u
CT1	25	131.5	19.0	2.14	13.75	15.5
CT2	40	169.5	23.6	3.04	17.99	16.9
CT3	65	252	25.8	3.13	18.8	16.6

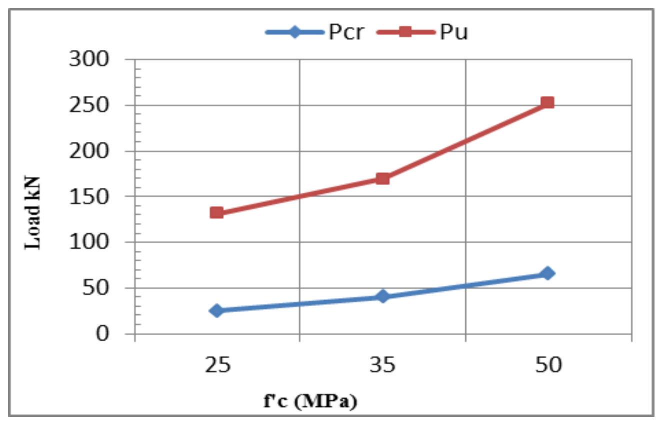


Fig.(6) *First Crack and Ultimate Load.*

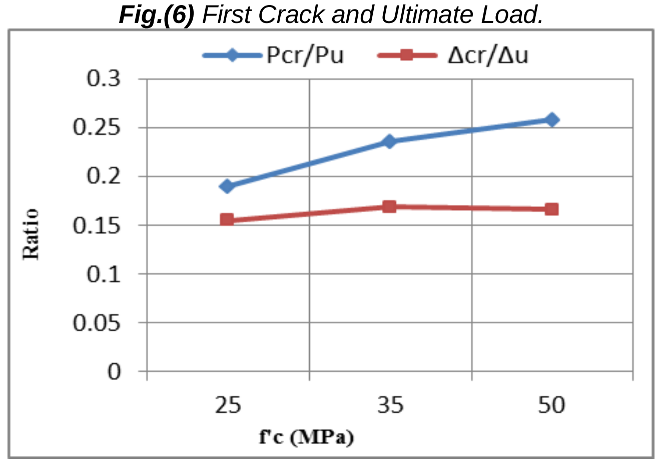


Fig.(7) *Percent of First Crack Load to Ultimate Load with Deflection for Beams.*

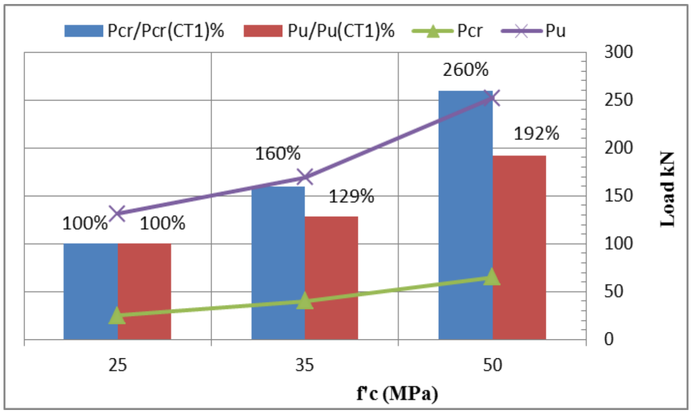
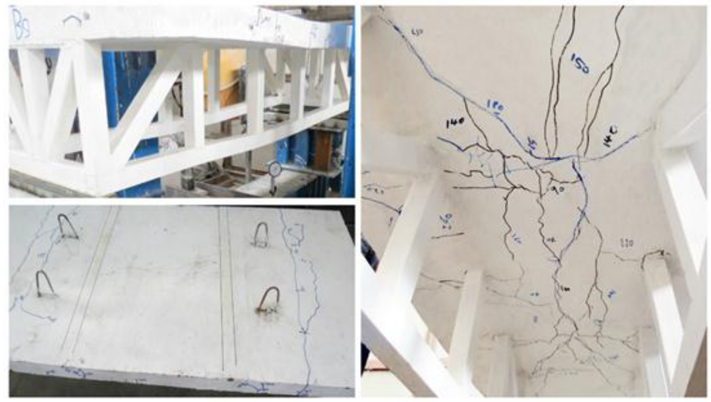


Fig.(8) *ratio of first cracking and ultimate load of various compressive strengths in relation to the control beam.*

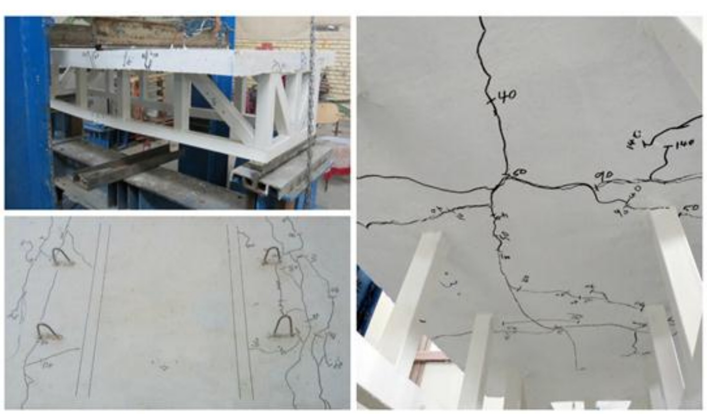
6.3.2 Cracking Patterns and Failure Mode

It has been observed that most beams have the same deformation, generally represents a shear failure or a combine shear-flexural failure in a concrete slab due to forming plastic hinges at the slab as shown in figure (9). Table(3) shows ultimate loads and failure modes results.

CT1



CT2



CT3

Fig. (9) *Cracks patterns for all specimens.*

Table 3. *Ultimate Loads and Failure Modes Results.*

Symbol of beam	P_u (kN)	Difference % With Control Beam In Ultimate Capacity	Failure Mode
CT1	131.5	N/A	Yielding in steel and shear-flexure crack in concrete
CT2	169.5	+28.89*	Yielding in steel and shear-flexure crack in concrete
CT3	252	+91.63*	Yielding in steel and shear-flexure crack in concrete

* *(+) Increase by ratio*

7 Finite Element Solution

A nonlinear finite element analysis of the tested specimens was made using ANSYS computer program Release 15. The main objective of this analysis is to compare results of experimental work with the present model using the ANSYS program.

7.1 Specimen Model Description and Material

A full composite veirendeel beam was modeled by different mesh for various elements that used in it as shown in figure (10) which describes the mesh density. This approach reduces the computer disk space and computational time requirements significantly. Four elements used to make modeling; these elements were BEAM188, LINK180, SOLID65 and SOLID185 to represent steel truss, reinforcement, concrete member and steel plates at loading points, respectively. All experimentally tested beams modeled as the same dimension in finite element analysis without interface element or contact element between concrete slab and steel truss member. The accuracy and efficiency of the computer model are mainly based on appropriate modeling of material characteristics. Concrete element (Solid 65) which requires linear isotopic, multi-linear isotopic and concrete parameters, while BEAM188 and LINK180 requires linear isotropic and bilinear isotropic properties to describe it on ANSYS program.

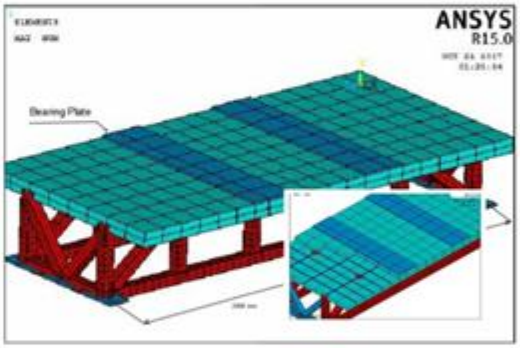


Fig. (10) *Geometry of the Numerical Model.*

7.2 Mesh Refinement and Loading with Boundary Conditions

To find the best mesh size, used three types of mesh are (844, 350 and 84 elements). The relation between mid-span deflection and the number of elements of the control beam noted for the same applied load of 50kN. The variation was about 9 % and acceptable when the number of elements increased from (844) as observed from the figure (12). The locations of load in model of finite element same that in the experimental for all specimens. The load used in this research was described by dividing the sum of the total distributed load on the number of upper nodes depending on the area enclosed by every individual node to represent the distributed load in ANSYS program as shown in figure (11). Loads up to the failure were applied gradually as desired by the Newton Raphson method.

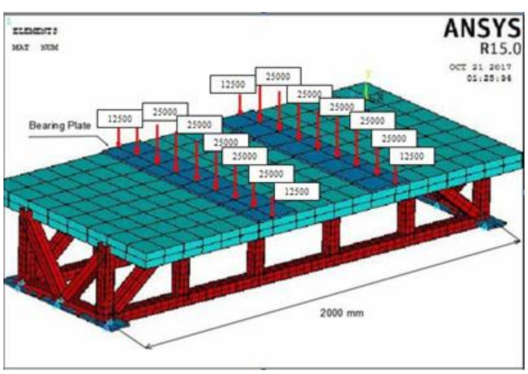


Figure (11) *Distribution of Applied Load and Boundary Conditions*

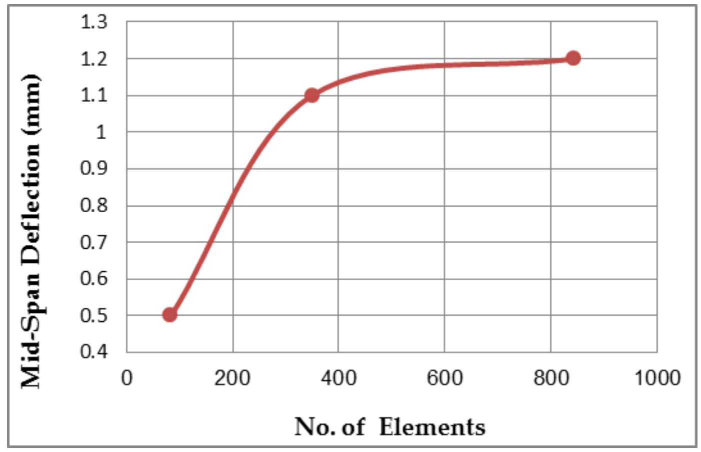
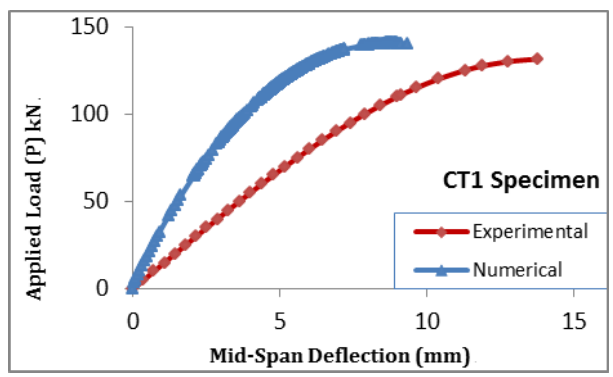


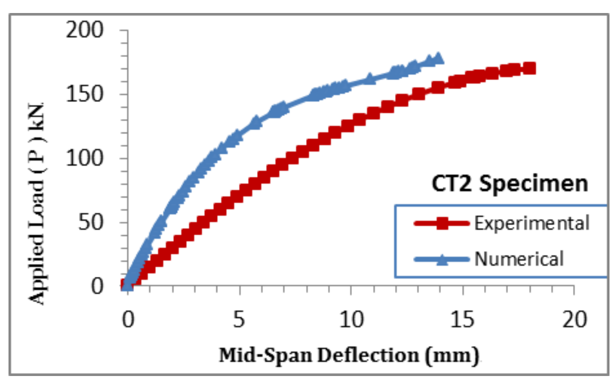
Figure (12) *Plot for convergence study*

7.3. Finite Element Results

7.3.1 Load-Deflection Curve Results

Figure (13) shows the F.E. results of load-mid span deflection curve compared with experimental result. The F.E. result of load-mid span deflection curve is stiffer than the result of experimental beam and converge at certain stage. The ultimate load of the F.E. (140.96kN) is larger than experimental (131.5kN) by about (7.19) % for CT1 specimen. While the ultimate load of the F.E. (178.028kN) is larger than experimental (169.5kN) by about (5.03) % for CT2 specimen. The ultimate load of the F.E. (285.09kN) is larger than experimental (252kN) by about (13.13) % for CT3 specimen.





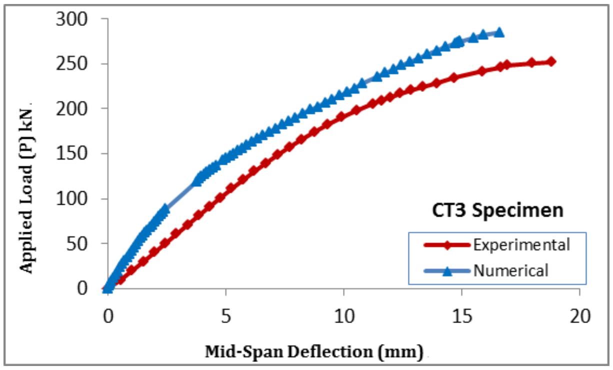
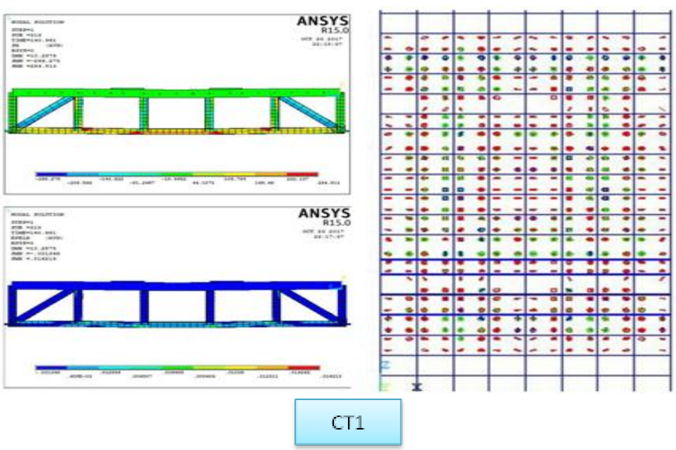
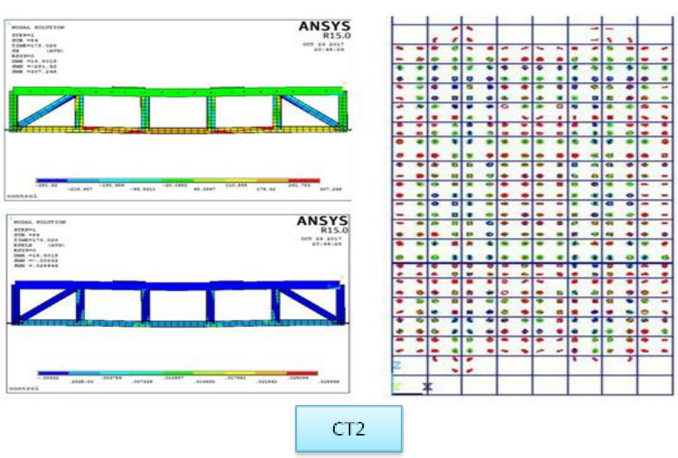


Figure (13) *Numerical And Exp. Load-Deflection Curve*

7.3.2 Cracking Behavior and Stresses

It has been observed that cracking behavior, stresses and strains similar to the experimental as shown in figures (14) below. The first crack obtained from the F.E. appear at loading 45kN, which is bigger than the experimental (25kN) for CT1. While the first crack obtained from the F.E. appear at loading 44kN, which is larger than the experimental (40kN) by (10) % for CT2 specimen. The first crack obtained from the F.E. appear at loading 80kN, which is larger than the experimental (65kN) by (23.07) % for CT3 specimen. That may be attributed to which cracks in experimental are measured when them visible.





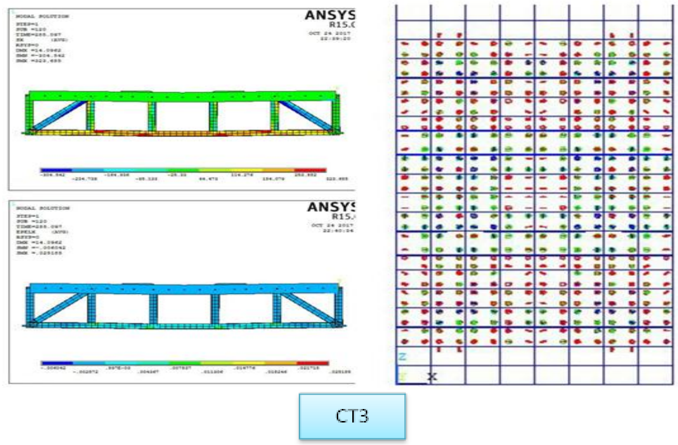


Fig. (14) *Cracks patterns, Stresses and Strains for all specimens.*

Table 4. *Experimental And Theoretical Ultimate Load and Loading at First Crack.*

Symbol of Beam	Loading of First Crack (kN)		(F.E./ Exp.)	Failure Load (kN)		(F.E./ Exp.)
	Exp.	Num.		Exp.	Num.	
CT1	25	45	1.8	131.5	140.9	1.07
CT2	40	44	1.1	169.5	178	1.05
CT3	65	80	1.23	252	285	1.08

8 CONCLUSIONS

1) The normal strain of the bottom chord of steel truss at mid-span exceeds the yield strain for all beams before compression failure of the top cord slab member. While The compression strain of the diagonal member of steel truss at the panel near support exceeds the yield strain for all beams also.
2) An increase concrete strength (f'c) from 25 MPa to 35 MPa leads to increase ultimate load capacity and cracking load by (28.89) % and (60.0) %, respectively. Whereas increase concrete strength from 25 MPa to 50 MPa leads to increase ultimate load capacity and cracking load by (91.63) % and (160) %, respectively.
3) The modelling of finite element illustrates overall exaggeration in the ultimate load by the range (0.2 to 13)% compared with experimental results. While the difference of flexural stiffness in load-deflection curve between finite element analysis and experimental work are ranging between (20.8-28.05) %.
4) The crack patterns, stresses, strains distribution and modes failure for all numerical beam are converge to the experimental work results.

REFERENCES

[1] Brattland, A., and Kennedy, D.J.L. 1986. Shrinkage and flexural tests of two full-scale composite trusses. Structural Engineering Report No. 143, Department of Civil Engineering, The University

of Alberta, Edmonton, Alta.

[2] ACI 318-14, “Building Code Requirements for Structural Concrete and Commentary,” American Concrete Institute, was adopted August 29, 2014, and published September 2014.

[3] Iraqi laboratory specifications No. 3868 of the Central Organization for Standardization and Quality Control.

[4] Iraqi specification No. 5, “Portland Cement,” Baghdad, 1984.

[5] Iraqi specification No. 45, “Natural Sources for Gravel that is Used in Concrete and Construction,” Baghdad, 1984.

[6] American Society of Testing and Materials, “Standard Specifications for Concrete Aggregates,” ASTM C-33, West Conshohocken, PA., 1986.

[7] ASTM C 494/C 494M-99, “Standard Specification for Chemical Admixtures for Concrete,” Annual Book of ASTM Standards, American Society for Testing and Materials, Vol.04.02, 1999.

[8] BS 5075 Part 1 and BS EN 934, Part 2.

[9] ASTM A 615/A615M-16, “Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement, ” 2016 Annual Book of ASTM Standards, Vol.01.04, ASTM International, West Conshohocken, PA, 2016, www.astm.org.

[10] ASTM A 370-05, “Standard Test Method and Definition for Mechanical Testing of Steel Products,” 2005 Annual Book of ASTM Standards, Vol.01.01, ASTM, Philadelphia, PA., 2005.

[11] ACI 211.4R – 93, “Guide for Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash,” American Concrete Institute Committee 211, Copyright, September 1.1993.

[12] ACI 214 – 02, “Evaluation of Strength Test Results of Concrete,” American Concrete Institute Committee 214, Copyright, June 27, 2002.

[13] American Concrete Institute, "Standard Practice for Selecting proportions for Normal, Heavyweight and Mass Concrete, ACI 211.1-91",pp. 6-38.