Behavior Of Reinforced Concrete Beams Without Web Reinforcement, Using Finite Element Analysis

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1-Introduction

Over the last 60 years, many researchers studied the shear performance of reinforced concrete beams [1-4]. The test variables used to study the shear behavior of reinforced concrete beam considerably found in literature denote to the parameters affecting the occurrence of shear failure, these parameters such as a longitudinal reinforcement ratio, compressive strength of concrete, shear span to depth ratio, type of loading and aggregate type, etc. Most of the researchers reported that the failure mode of concrete beam is strongly dependent on the shear span to depth ratios.

As detailed by the ACI-ASCE committee, depended on the review of different models, the shear strength of reinforced concrete beams depends on the concrete compressive strength, the span-depth ratio (a/d) and the percentage of the longitudinal reinforcement, [(5) Clark, A.P] explained that the shear strength of reinforced concrete beams is affected by concrete compressive strength ($f'c$), the shear span-depth ratio (a/d) and the percentage of longitudinal reinforcement.

[(6) Kwak, Y.K., et al] presented twelve tests were carried out on reinforced concrete beams with steel fiber-volume fractions (0,0.5% and 0.75%), compressive strength of concrete (31 and 65 Mpa) the ratio of shear span-depth (a/d) (2,3 and 4). The results showed the shear strength increased with increasing fiber volume, increasing the compressive strength of concrete and decreasing (a/d).

An experimental and numerical study presented in [(7) Sudheer Reddy, et al] to predict the shear capacity of high strength concrete of sixteen beams with different shear span- depth ratio (1,2,3 and 4) without web reinforcement. Ansys software was used to model the tested beams. The FE model results were compared with the results of tests data, the tested results of the shear strength were closer to that evaluated using an Ansys model for the beams, also the results showed the shear capacity increased with decreasing in shear span-depth ratio (a/d).

The present study investigates the behavior of three rectangular reinforced concrete beams without shear reinforcement by using three-dimensional brick elements for concrete and link elements for longitudinal reinforcement. Comparing the ultimate shear force, shear force-deflection curve with available experimental data [(8) Thamrin, R.,et al] has been made to check the validation of the application of Ansys software, also ,a parametric study is done to investigate the effect of concrete compressive strength and shear span- depth ratio (a/d) on the RC beams.

2-Finite Element Modelling

The present study used the finite element software Ansys (V15.0), which utilized to analyse the three dimensional model. For modelling reinforced concrete beams, the concrete was modelled by utilizing the 8-noded brick element (solid 65), this element has three degrees of freedom at each node (translations in the x, y and z directions) figure (1). Element (solid 65) is a capable handling nonlinear behavior, crushing in compression, modifying cracks in tension and in three orthogonal directions, and plastic deformation [(9) ANSYS Manual].

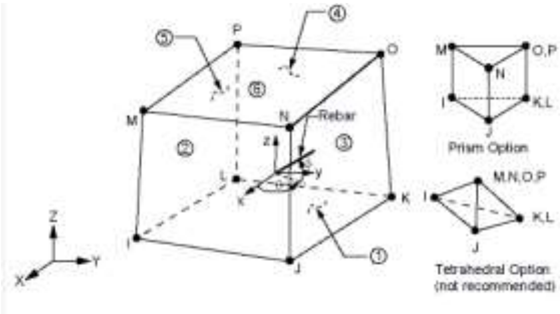


Figure (1) Solid (65) element [(9) ANSYS Manual]

The reinforcement is modelled by using the 2-noded element (link 180) with three degrees of freedom at each node (translations in the x, y and z directions) figure (2). Element (link 180) is a uniaxial tension, compression element, capable of handling plasticity, swelling, creep and stress stiffening [(9) ANSYS Manual].

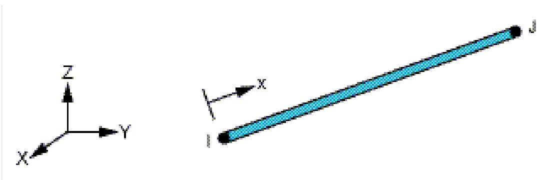


Figure (2) Link (180) element [(9) ANSYS Manual]

The supports and loading plates are modelled by using a 8-noded element (solid 185) with three degrees of freedom at each node (translations in the x, y and z directions) figure (3). Element (solid 185) is capable of handling plasticity, swelling, creep and stress stiffening [(9) ANSYS Manual].

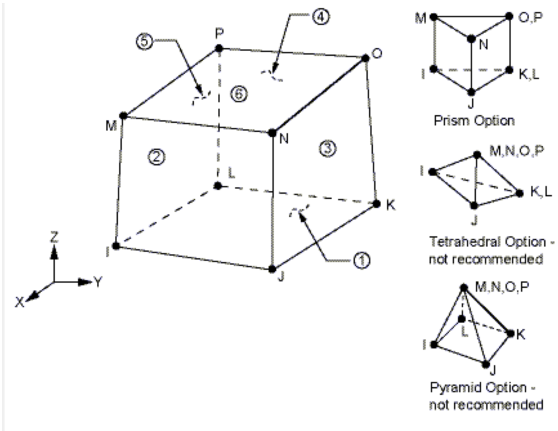


Figure (3) Solid (185) element [(9) ANSYS Manual]

3-Material Modelling

1) Concrete

To represent concrete in compression, The Ansys software requires the uniaxial stress-strain relationship. Numerical equations explained by equations (1) to (4) were used to construct the uniaxial stress-strain relationship for concrete in compression [(10) Desayi, P., et al]. Figure (4) shows a simplified compressive uniaxial stress-strain curve for concrete.

$$f'c = \frac{\varepsilon Ec}{1+\left(\frac{\varepsilon}{\varepsilon_0}\right)^2} \qquad \text{for} \quad \varepsilon_1 \le \varepsilon \le \varepsilon_0 \quad ....(1)$$

$$\varepsilon_0 = \frac{2f'c}{E_c} \qquad .... (2)$$

$$\varepsilon_1 = \frac{0.3f'c}{E_c} \qquad \text{……... (3)}$$

$$E_c = \frac{\sigma}{\varepsilon} \qquad \text{for} \quad 0 \le \varepsilon \le \varepsilon_1 \quad \text{……... (3)}$$

Where:

$\sigma =$ stress at any strain $\varepsilon, N/mm^2$

$\varepsilon =$ strain at stress σ

$\varepsilon_0 =$ strain at the ultimate compressive strength $f'c$

ε_1 = strain corresponding to (0.3 $f'c$)

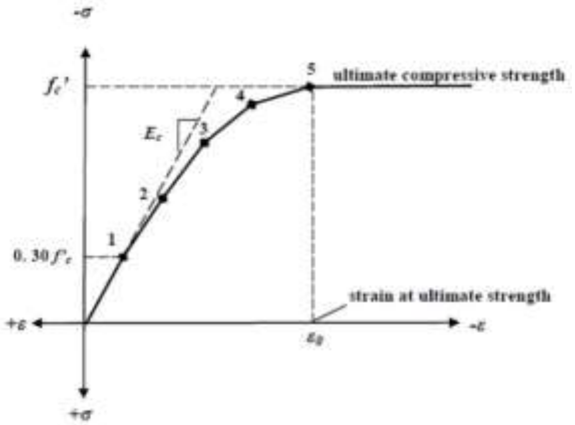


Figure (4) Typical uniaxial stress-strain curve for concrete in compression

In tension, the stress-strain relationship for concrete is linear elastic and increases with an increase in tensile strain up to concrete cracking, after this point, the tensile stress decreases gradually to zero as the concrete softens [(11) Bangash, M.Y.H].

The modulus of elasticity E_c , can be evaluated from the empirical formula [(12) ACI 318-2005]

$$E_c = 4700\sqrt{f'c}$$

Where:

$f'c =$ concrete compressive strength, N/mm^2

The ultimate tensile strength (modulus of rupture) is taken as $fr = 0.7\sqrt{f'c}$

A shear transfer coefficient (β), which represents a shear strength reduction factor for concrete across the face of a crack, is introduced to represent the efficiency of concrete to transfer shear force across the crack interface [(9) ANSYS Manual], Typical shear transfer coefficients range from 0 to 1, the value (0) used to represent a smooth crack, and the value (1) used to represent a rough crack.

2) Steel Reinforcement

The behavior of steel reinforcement is assumed to be elastic-perfectly plastic relation which ignores the strain hardening region. The uniaxial stress-strain relationship is assumed to be similar in compression and in tension as shown in figure (5).

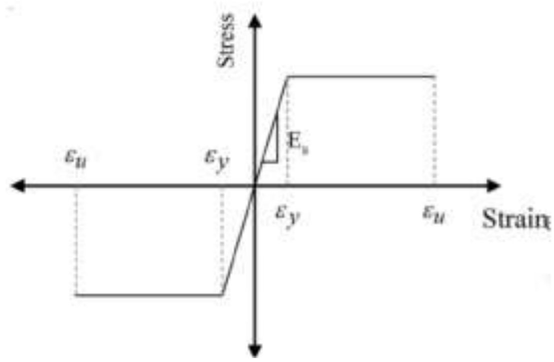


Figure (5) Uniaxial stress-strain curve for steel reinforcement

4-Method of Analysis

4-1 Modelling of RC Beams

For the validation of the modelling and analysis method using Ansys software, three rectangular reinforced concrete beams specimens used by [(8) Thamrin, R.,et al] are considered. The RC beams are modelled using Ansys (v15.0) with the details given in [(8) Thamrin, R.,et al]. The geometry and dimension of the beams are shown in figure (6). The details of the specimens and the properties of the materials are given in table (1) and (2) respectively.

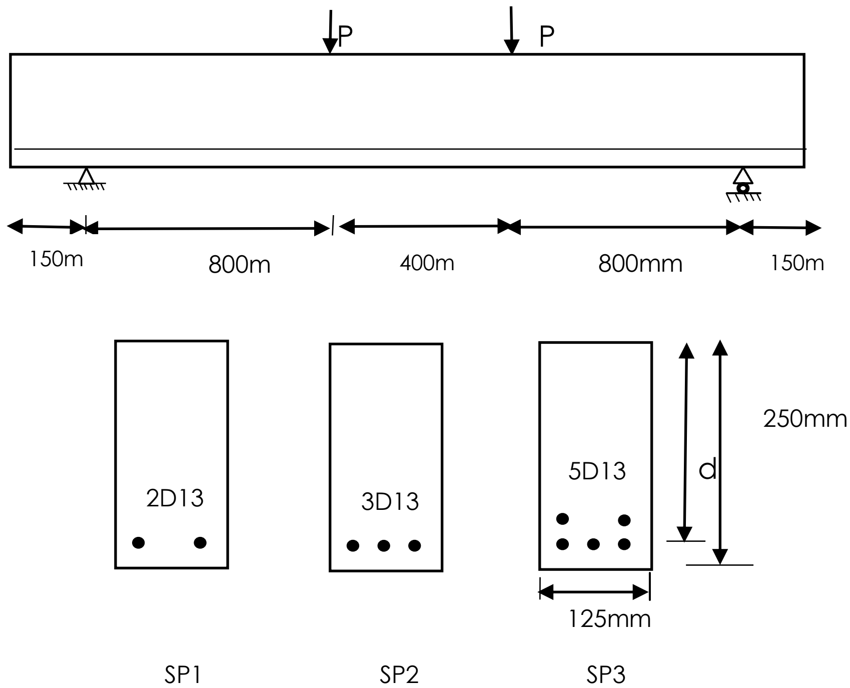


Figure (6) Dimensions of the specimens

Table (1) Details of the specimens

Specime-ns	Length (mm)	Width (mm)	Height (mm)	Shear Span (mm)	Effective Depth (mm)	Shear span-depth (a/d)	Longitud-inal Steel ratio%
SP1	2300	125	250	800	219	3.7	1
SP2	2300	125	250	800	219	3.7	1.5
SP3	2300	125	250	800	212	3.8	2.5

Table (2) Properties of materials

Material	Property	Value
Concrete	Compressive strength $f'c, N/mm^2$	32
	Modulus of rupture$fr, N/mm^2$	3.96
	Modulus of elasticity $Ec, N/mm^2$	26587
	Poisson's ratio υ	0.2
Steel reinforcement	Yield strength $fy, N/mm^2$	550
	Modulus of elasticity $Es, N/mm^2$	$204*10^3$
	Poisson's ratio υ	0.3
Steel plate	Modulus of elasticity $Es, N/mm^2$	$200*10^6$
	Poisson's ratio υ	0.3

The FE model of the specimen (SP1, SP2, SP3) in Ansys is shown in figure (7).

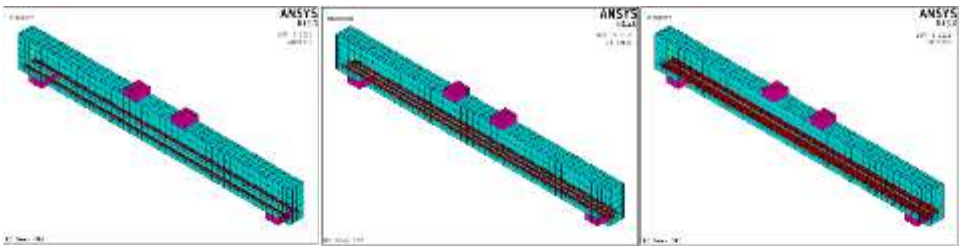


Figure (7) FE modelling of the specimens

4-2 Finite Element Modelling of Steel Reinforcement

For modelling steel reinforcement, the discrete model is applied. In the present study, perfect bond is assumed between materials. Figure (8) shows the discrete model for steel reinforcement.

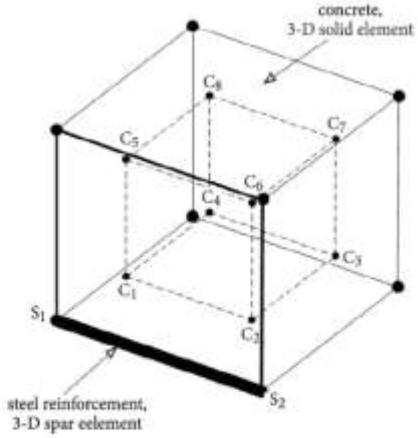


Figure (8) Discrete model for steel reinforcement.

4-3 Boundary Conditions and Loads

Following the testing procedures conducted by [(8) Thamrin, R.,et al], simply supported boundary conditions were modelled in such a way that a hinge and roller is created. The force is applied across the centreline at each node on the steel plate. The boundary conditions for supports and loadings are shown in figure (9).

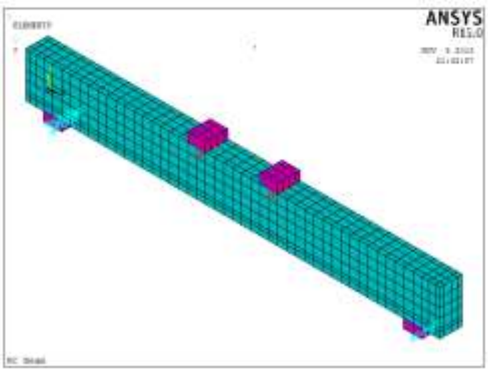


Figure (9) The boundary conditions of the specimens

4-4 Analysis Termination Criteria

In nonlinear analysis, the total load applied to a finite element model is divided into a series of load increments called load steps. At the completion of each incremental solution, the stiffness matrix of the model is adjusted to reflect nonlinear changes in structural stiffness before proceeding to the next load increment. In this study, for the reinforced concrete solid elements, convergence criteria were based on displacement, and the convergence tolerance limits were initially selected by the ANSYS program. It was found that the convergence of solutions for the models was difficult to achieve due to the nonlinear behavior of reinforced concrete. Therefore, the convergence tolerance limits were increased to a maximum of 5 times the default tolerance limits (5% for displacement checking), in order to obtain convergence of the solutions. In addition to a maximum number of iterations for each increment of load is indicated to terminate the nonlinear solution if the convergence tolerance has not been achieved. A maximum number of iterations equal to (50) has been used, because it is found that this value is generally sufficient to predict the solution's divergence or failure.

5-Finite Element Results

5-1 Shear Force-Deflection Curve

Figure (10) shows the experimental [(8) Thamrin, R.,et al] and finite element curves obtained for the rectangular RC beams (SP1, SP2 and SP3), in this figure the shear force is plotted against the mid-span deflection. For all the specimens, the shear force obtained by experimental test and that predicted by the present FE solutions is listed in table (3). It can be noticed from figure (10) and table (3) that the present numerical solutions are in good agreement with the experimental results. Figure (11) shows varying vertical displacement along the beams (SP1, SP2 and SP3) at ultimate shear force.

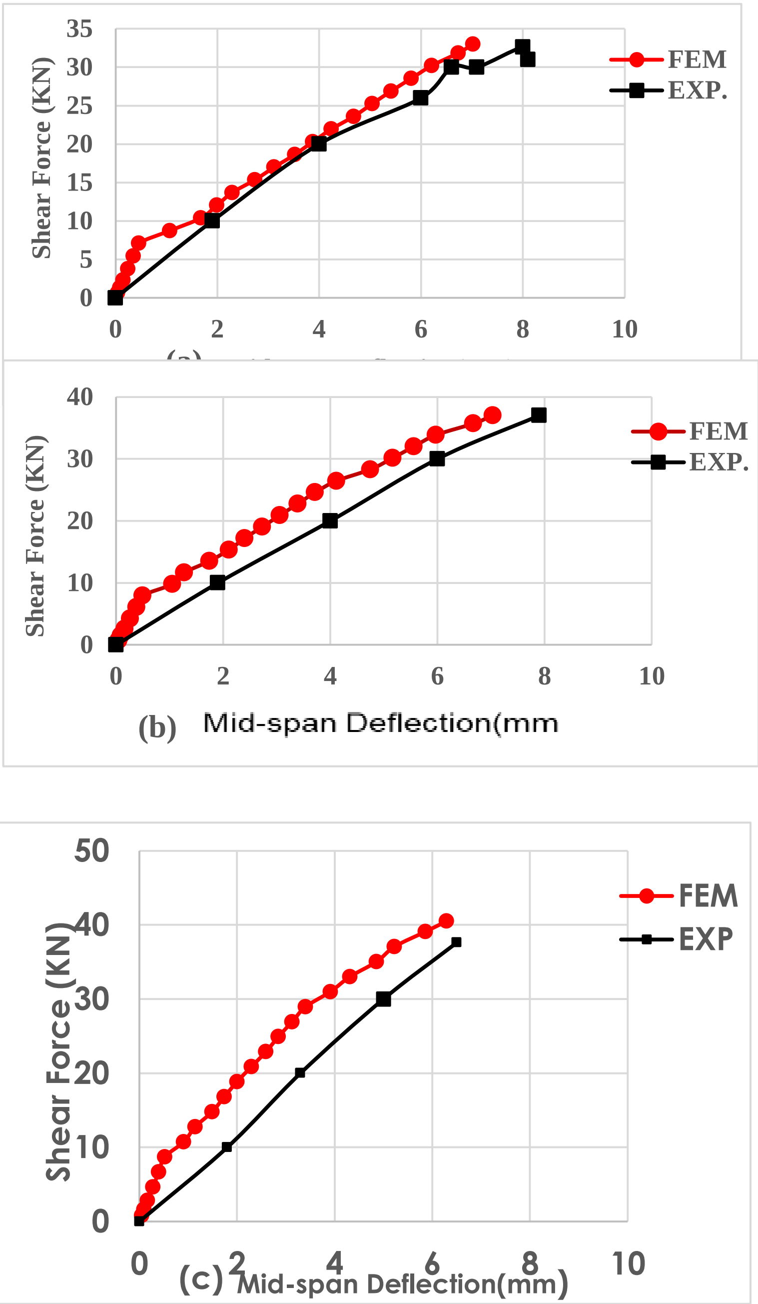
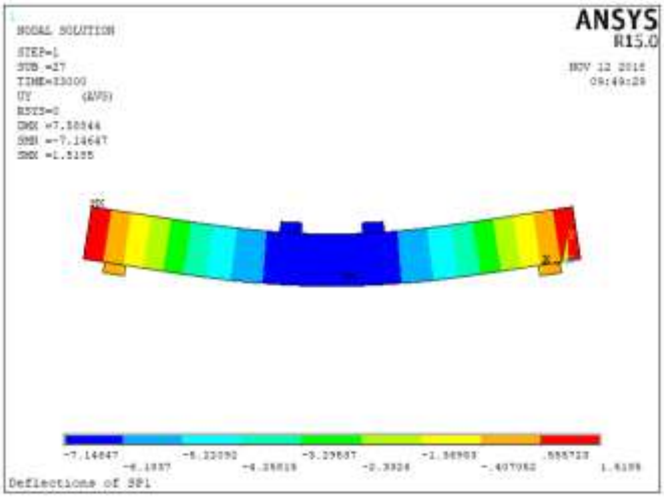


Figure (10) Shear force-mid-span deflection for a) SP1, b) SP2 and c) SP3

The finite element shear force-deflection plots in general are stiffer than the experimental plots. The higher stiffness's in the finite element models can be resulting from various effects. First, in the finite element models, the bond between the concrete and steel reinforcing is assumed to be perfect, but this assumption would not be valid for the experimental specimens. Next, the finite element models do not contain the micro cracks, the micro crack decrease the stiffness of the experimental beams. Thus, the total stiffness of the finite element models is expected to be higher than for the experimental beams.

Table (3) Comparisons between experimental shear force and FE shear force

Specimen	Shear force (KN)		Exp. /FE
	Exp.	FE	
SP1	31	33	0.939
SP2	37	37	1
SP3	37.6	40.5	.928



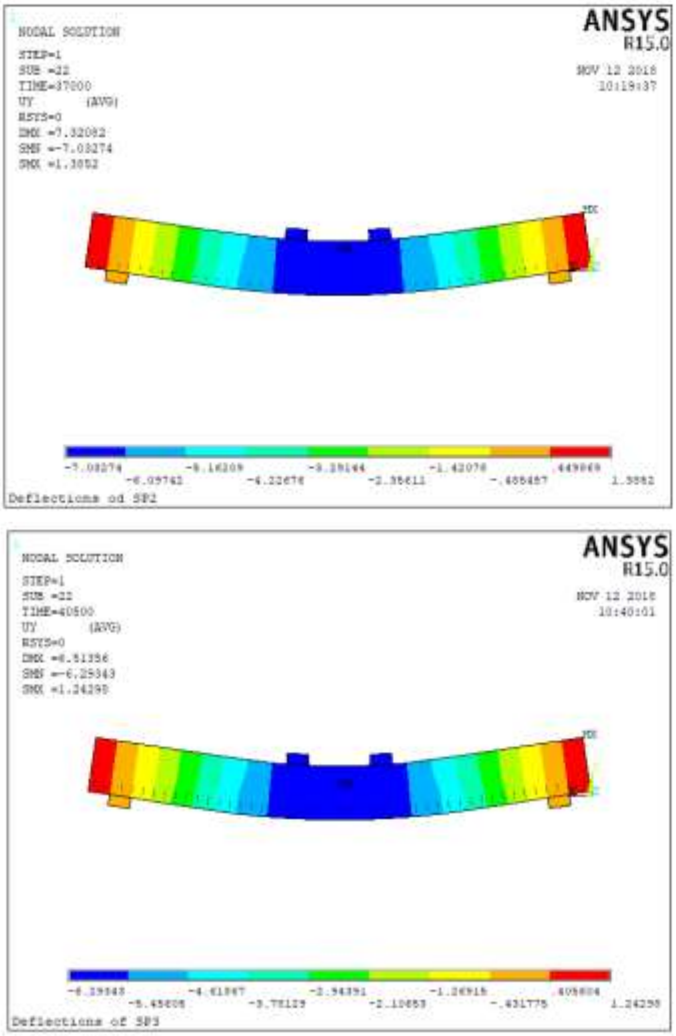


Figure (11) The variation of vertical displacement along the beams (SP1, SP2 and SP3) at ultimate shear force.

Figure (12) shows the finite element results of the three specimens, they indicate the effect of steel ratio (ρ) on the behavior of RC beams, also it can be noticed the increasing of shear capacity and stiffness in beam SP3 of higher steel ratio.

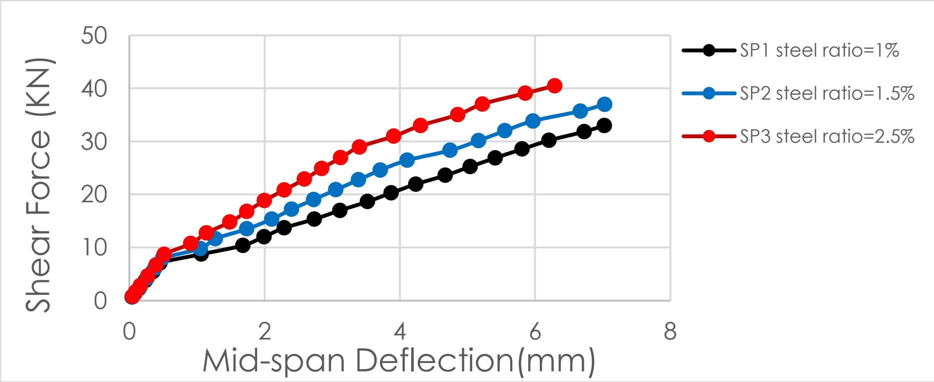
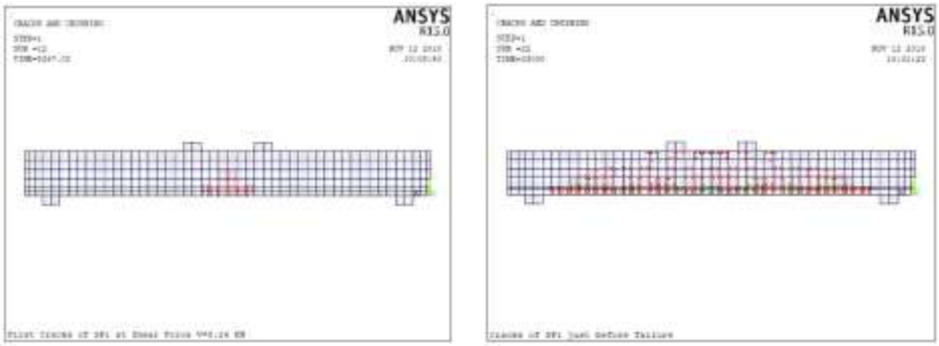


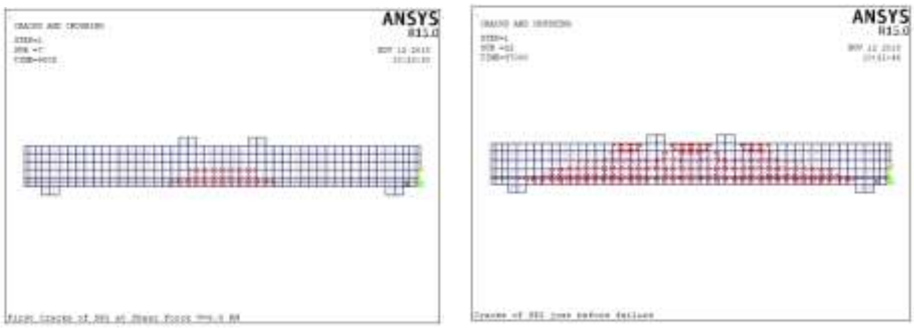
Figure (12) Effect of steel ratio (ρ%) on RC beams

5-2 Crack Patterns

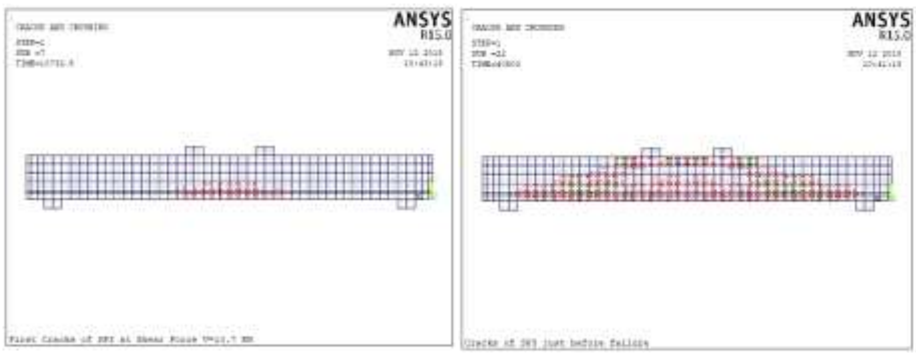
Figure (13 (a), (b) and (c)) shows the growth of cracks within the RC beams. As the applied load exceeded the cracking load (shear force V=8.16 kN for SP1, V=9.8 KN for SP2, and V=10.7 KN for SP3) flexural cracks started in the areas in which concrete tensile stresses reached modulus of rupture. The first cracks appeared in the constant moment area. They are vertical flexural cracks. It was observed that flexural crack development was flat and sudden. This indicates that the tensile stress relaxation is not functioning properly, leading to a sudden stress drop. At larger loading, flexural shear cracks appeared. Subsequent cracking occurred as more load was applied to the beam. Cracking increased and extended in the constant moment area. Then the beam started cracking out towards the supports, and expanded towards the compression zone.



(a) Crack Patterns of SP1



(b) Crack Patterns of SP2



(c) Crack Patterns of SP3

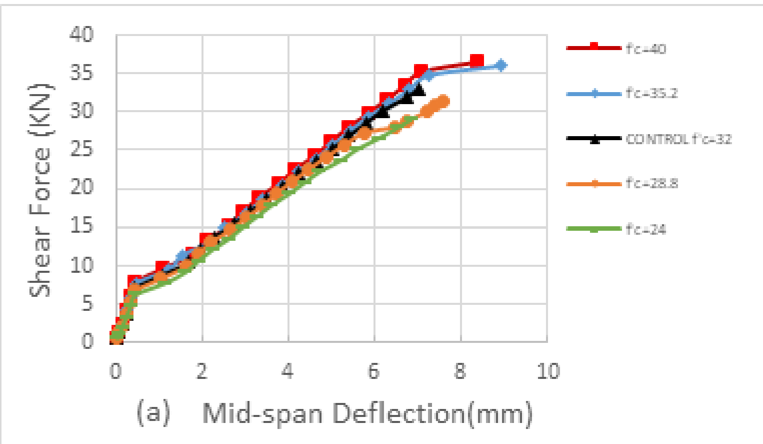
Figure (13) Crack Patterns of the Specimens

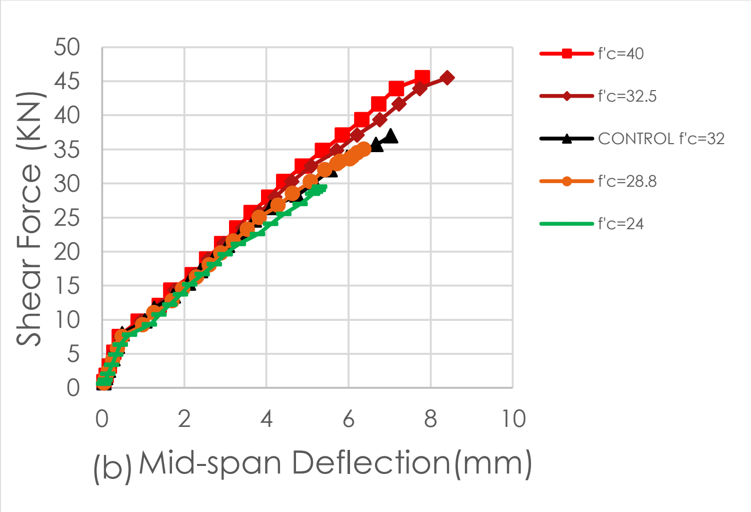
5-3 Parametric Study

The behavior of a rectangular reinforced concrete beams is affected by several parameters. In the current study the beams (SP1, SP2 and SP3) have been employed in a numerical study to show the effects of some parameters on the nonlinear FE solution. These parameters include the effect of concrete compressive strength and shear span-depth ratio.

5-3-1 Effect of Concrete Compressive Strength

In order to investigate the effect of concrete compressive strength "$f'c$" on the RC beam behavior, SP1, SP2, and SP3 have been analyzed with different values of concrete compressive strength. Figure (14) shows the effect of "$f'c$" on the shear force-deflection curve for SP1, SP2 and SP3. As the concrete compressive strength increased the shear strength of the beam increases and the deflection deceases. For all the specimens, the ultimate shear force obtained for different "$f'c$" are listed in table (4).





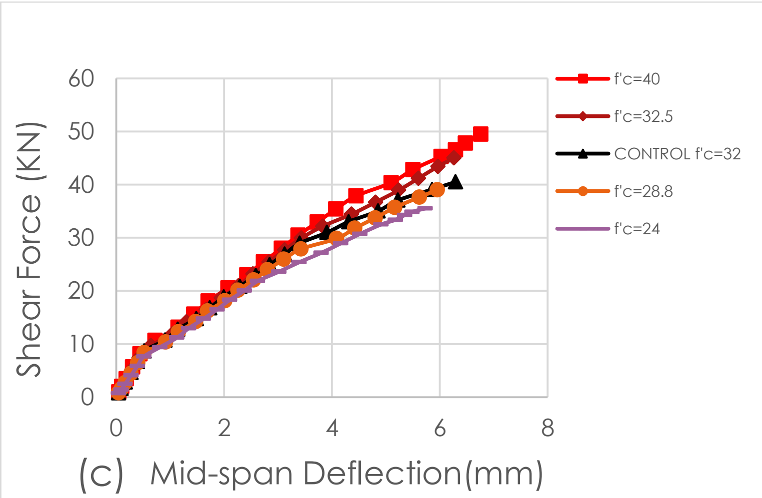


Figure (14) Effect of concrete compressive strength on a) SP1 b) SP2 c) SP3.

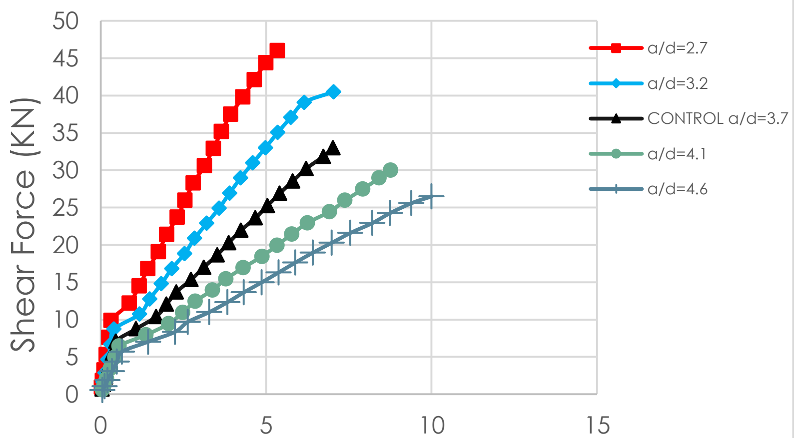
Table (4) Effect of concrete compressive strength on ultimate shear force

Speci-men	Shear force Pu (KN), (Ratio Pu /P control)				
		Decreasing $f'c$		Increasing $f'c$	
		25%	10%	10%	25%
	$f'c$=32N/mm^2 P control	$f'c$=24 N/mm^2 Pu, $(\frac{Pu}{\text{P control}})$	$f'c$ = 28.8 N/mm^2 Pu, $(\frac{Pu}{\text{P control}})$	$f'c$=35.2 N/mm^2 Pu, $(\frac{Pu}{\text{P control}})$	$f'c$=40 N/mm^2 Pu, $(\frac{Pu}{\text{P control}})$

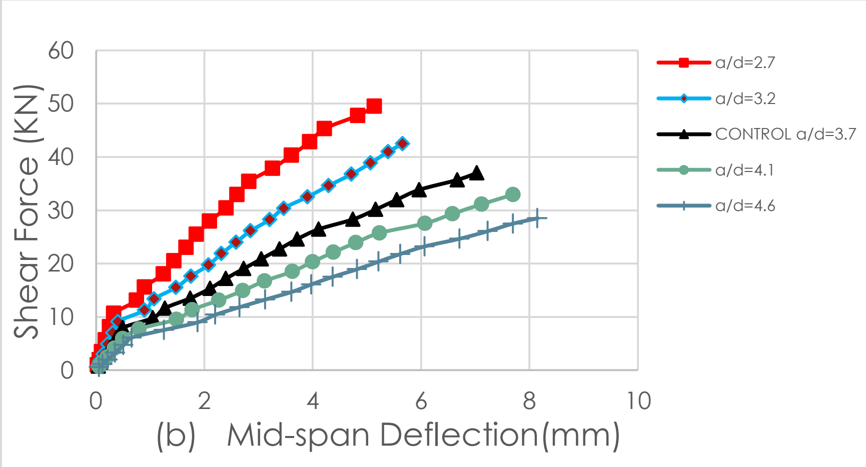
SP1	33	29 (.878)	31.5 (0.95)	36 (1.09)	36.5 (1.2)
SP2	37	29.5 (0.79)	35 (0.94)	45.5 (1.23)	46 (1.24)
SP3	40.5	35.5 (0.87)	39 (0.96)	45 (1.1)	49.5 (1.22)

5-3-2 Effect of Shear Span-Depth Ratio

Figure (15) shows the shear force-deflection response of (SP1, SP2 and SP3) for various shear span-depth ratio. The results are listed in table (5), based on the results of the analysis, it can be noticed that the significant effect of shear span- depth ratio (a/d) on the behavior of the specimens, especially on the deflection. As the shear span to depth ratio increased, the shear strength of the beams decreases and the deflection increases.



(a) Mid-span Deflection(mm)



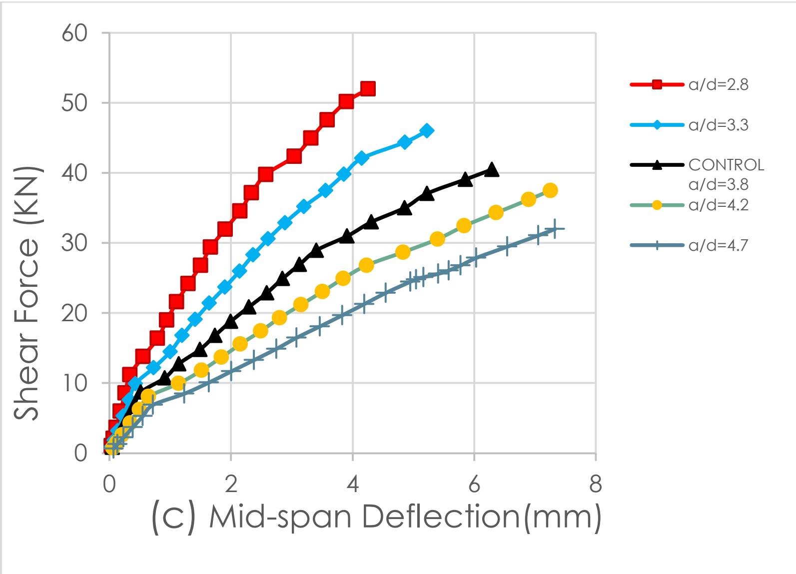


Figure (15) Effect of shear span-depth ratio on a) SP1 b) SP2 c) SP3.

Table (5) Effect of shear span to depth ratio on ultimate shear force

Specim-en	Shear force Pu (KN), (Ratio Pu /P control)				
		Decreasing a/d		Increasing a/d	
		25%	10%	10%	25%

	P control	Pu, ($\frac{Pu}{P\ control}$)	Pu, ($\frac{Pu}{P\ control}$)	Pu, ($\frac{Pu}{P\ control}$)	Pu, ($\frac{Pu}{P\ control}$)
SP1	33	46 (1.39)	40.5 (1.2)	30 (0.9)	26.5 (0.8)
SP2	37	49.5 (1.3)	42.5 (1.14)	33 (0.89)	28.5 (0.77)
SP3	40.5	52 (1.28)	46 (1.13)	37.5 (0.92)	32 (0.79)

6- Conclusions

The essential concluding remarks that have been carried out from the results of the FE analysis may be abbreviated as:

1- Based on the results of the available experimental data with comparison with the finite element results obtained by Ansys software (v 15.0), it is shown that the adopted FE modelling can be utilized to predict the behavior of such RC beams.

2- The Numerical results indicated that the shear force-deflection curve and the ultimate shear force obtained by FE modelling are in good agreement with the experimental results. The maximum ratio of the experimental ultimate shear force to the numerical ultimate shear force has an average value of (0.928).

3- Based on the results obtained by FE modelling of the specimens, it was found that the ultimate shear capacity increases with increase in concrete compressive strength and decrease in shear span-depth ratio decrease.

4- The ratio of shear span-depth ratio had the significant effect on the behavior of RC beams.

References:

[1] Bresler, B. and MacGregor, J.G., 1967. "Review of concrete beams failing in shear". Journal of the Structural Division, (Vol. (93) No. (1), pp. 343-372).

[2] Zsutty, T.C., 1968. "Beam shear strength prediction by analysis of existing data". Journal Proceedings (Vol. (65), No. (11), pp. 943-951).

[3] Placas, A., and Regan, P. E. 1971. "Shear failure of reinforced concrete beams". ACI J., (Vol. (68) No. (10): 763-773).

[4] Kani, G.N.J., 1964. "The riddle of shear failure and its solution". Journal Proceedings (Vol. (61), No. (4), pp. 441-468).

[5] Clark, A.P., 1951. "Diagonal tension in reinforced concrete beams". Journal Proceedings (Vol. (48), No. (10), pp. 145-156).

[6] Kwak, Y.K., Eberhard, M.O., Kim, W.S. and Kim, J., 2002. "Shear strength of steel fiber-reinforced concrete beams without stirrups". ACI Structural Journal, (Vol. (99) No. (4), pp. 530-538).

[7] Sudheer Reddy, R. Rao and G. Rao T.D 2011. "Evaluation of Shear Resistance of High Strength Concrete Beams without Web Reinforcement using ANSYS", APRN Journal of Engineering and Applied Sciences (Vol. (6), No. (2), ISSN-1819-6608)

[8] Thamrin, R., Tanjung, J., Aryanti, R., Nur, O.F. and Devinus, A., 2016. "Shear strength of reinforced concrete T-beams without stirrups". Journal of Engineering Science and Technology, (Vol. (11) No. (4), pp. 548-562).

[9] "ANSYS" Manual, Version 15.0, U.S.A. 2014

[10] Desayi, P. and Krishnan, S., 1964, March. "Equation for the stress-strain curve of concrete". Journal Proceedings (Vol. (61), No. (3), pp. 345-350).

[11] Bangash, M.Y.H., 1989. "Concrete and concrete structures: Numerical modelling and applications". Elsevier Science Publishers Ltd., London, England.

[12] ACI Committee 318, Building Code Requirements for Structural concrete "ACI 318-14, ACI 318R-2014", American Concrete Institute, 2014.

Abstract:

This study presents a numerical study to simulate the shear behavior of reinforced concrete beam using finite element (FE) modelling. A three-dimensional finite element (FE) model has been developed by using computer program ANSYS version (15.0) in order to investigate the behavior of three rectangular reinforced concrete beams with different longitudinal reinforcement ratio (1,1.5, 2.5%) without struipps, in terms of crack initiation, propagation and pattern, ultimate shear force as well as shear force-deflection relationship. The analytical results of shear force -deflection response have been compared with available experimental tests. In general, good agreement between the finite element solutions and experimental results have been obtained. The maximum ratio of the experimental ultimate shear force to the numerical ultimate shear force has an average value of (0.928). Parametric studies have been carried out to investigate the effect of compressive strength of concrete (f^' c) and shear span to depth ratio (a/d).

Keywords; Rectangular reinforced concrete beam. Shear capacity. Finite Element Modelling.

الملخص :

هذه البحث يقدم دراسة عددية لتمثيل سلوك القص للأعتاب الخرسانية المسلحة باستخدام طريقة العناصر المحددة. تم تطوير نموذج العناصر المحددة ثلاثي الابعاد باستخدام برنامج (Ansysv15.0) وذلك لتقصي سلوك القص لثلاث اعتاب خرسانية مع نسب حديد التسليح الطولي (١، ١.٥ ، ٢.٥%) وبدون تسليح القص. هذا السلوك يتضمن دراسة التشققات ودراسة اقصى حمل قص ومنحني قوة القص-الانحناء.

تم دراسة النتائج ومقارنتها مع النتائج العملية المتوفرة، هذه النتائج تتمثل بأقصى قوة قص ومنحني قوة القص-الانحناء. ومن خلال المقارنة وجد ان هنالك تقارب في النتائج وتبين إمكانية استخدام نموذج العناصر المحددة لتمثيل النماذج. وكانت أكبر نسبة بين قوة القص المتحصلة من النتائج العملية الى قوة القص من طريقة العناصر المحددة هي (٠.٩٢٨)، وتم أيضا دراسة ثوابت معينة لتقصي تأثير هذه الثوابت على سلوك العتبات .