Behavior of Reinforced Concrete Composite Beams with Embedded Prestressed Concrete Prisms Using Nonlinear Finite Element Analysis

Dr. Laith Khalid Al-Hadithy
Engineering College
Al-Nahrain University

Hamza Sadiq Abdal-Kareem
M.Sc. Civil Engineering

Abstract:

The investigation described herein deals with a theoretical study of the flexural behavior of simply supported composite beams consisting of precast prestressed concrete prisms as tension reinforcement in reinforced concrete, by developing a non-linear three-dimensional finite element model.

Eight-node isoparametric brick elements with and without smeared steel reinforcement are used to model the reinforced concrete medium and the precast concrete prism respectively, using the corresponding material properties and considering the appropriate tensile cracking and compressive crushing phenomena for each , while a two-node three-dimensional axial element capable of plastic post-yield deformation is used for modeling the prestressing steel strands. Perfect bond is assumed for all concrete-concrete and steel-concrete contact surfaces.

with its qualified brick and axial elements is used to predict the load-deflection behavior of four typical simply supported beams using such composite system and varying in cross-sectional whole dimensions and areas of precast prisms, prestressing strands and nonprestressed rebars. That behavior is compared with behavior of four previously tested corresponding specimens to verify the accuracy of the finite element model in the linear and post-cracking stages.

A parametric study comprizing effects of the relative eccentricity of the prestressing strands and the geometric state of precast prestressed prisms on flexural behavior of this composite system is preformed to compute these effects on stiffness and ultimate resistance proving their major role after cracking which depends on the relative quantities of precast prisms and prestressing strands.

Accurate results of the present finite element model has proved its effectiveness and reliability in the analysis of such composite systems, hence giving motive to widen its application in that field.

Notations:

b, d, h	breadth, effective depth, and total depth of a composite beam cross-section
Ars(comp.), Ars(tensile)	cross-sectional area of non-prestressed reinforcing steel bars in compression and in tension, respectively
Apc	cross-sectional area of precast prestressed prisms
Aps	cross-sectional area of prestressing steel strands
Ec, Epc	Young's modulus of in-situ and precast concretes, respectively
Es, Eps	Young's modulus of nonprestressed steel rebars and prestressing steel strands, respectively
fc', fpc'	compressive strengths of in-situ and precast concretes respectively
ft, fpt	tensile strengths of in-situ and precast concretes respectively
fy, fpy	yield stresses of nonprestressed steel rebars and prestressing steel strands, respectively.
fu, fpu	ultimate stresses of nonprestressed steel rebars and prestressing steel strands, respectively
fpe	effective prestressing stress for prestressing steel strands
βo, βc	shear transfer coefficients in concrete for open and closed cracks, respectively
υc, υpc	Poisson's ratio of in-situ and precast concretes, respectively
υs, υps	Poisson's ratio of nonprestressed steel rebars and prestressing steel strands, respectively

1. Introduction:

Composite beams of precast prestressed concrete units encased in ordinary reinforced concrete envelopes offer a number of advantages in both design and construction. They can be used in buildings and bridges for the benefit of increased load-carrying capacity.

Another advantage of this production-oriented and economic material is that it can be used in places where direct prestressing is inconvenient or where flexural cracks must be controlled without affecting the moment redistribution capacity of the structure.
The benefit of using embedded precast prestressed concrete elements in reinforced concrete construction have become apparent through some research and testing done in various countries(1,2,3,4,5,6,7,8). On that bases, conventional reinforcement in pavement, building and bridge slabs, rectangular concrete beams, columns, continuity connections and other structures was replaced by small-sized prestressed concrete elements. Evans and Parker (1) elucidated that good bond between prestressed and in-situ concretes can be obtained if the jointing surface is sufficiently roughened, and complete monolithic action will be exhibited by a beam bonded in this way. Evans and Kong (3) extended the previous work (1) to investigate the crack propagation in such composite concrete members and concluded that the differential shrinkage, between the two elements may affect cracking loads either to advantage or adversely. Bishara, and Almeida, (6) studied experimentally the behavior on flexural cracks of embedding precast prestressed elements into simply supported reinforced concrete beams and concluded that for the same level of load, maximum crack widths are smaller in beams where prestressed elements were used as tension reinforcement. Mawal, (8) conducted tests carried out on such composite simply supported and continuous beams; He concluded that the range of linearity of deformation with respect to load increases with the increase in the effective prestressing force and the area of the prestressed element, and it is possible (for continuous beams) to predict the plastic hinge rotation and the degree of redistribution with the help of the proposed moment curvature relationship.
While a lot of work was done within the last two decades in the field of finite element analysis of precast members and systems (9,10,11,12,13,14,15), no analytical or numerical investigation on composite reinforced concrete members with embedded precast prestressed elements has been found. On the other hand, model testing can give an insight into their structural behavior, but it is a very costly and time consuming procedure. Accordingly, the present research work is carried out to develop a numerical procedure based on the finite element method for the investigation of the overall structural behavior of such composite concrete flexural members with special attention to material nonlinearities (cracking and crushing of concrete in tension and compression respectively and yield of steel). The results obtained from the present finite element analysis -using the analysis system computer program ANSYS (16) Version 5.4- are compared with experimental results of Mawal's beams (8) to verify the accuracy of the present numerical treatment.
Moreover, the results of an extensive parametric study to investigate the effects of the eccentricity of the resultant prestressing forces within the precast prestressed prisms embedded in the whole composite beam and the geometric states of the precast prestressed prisms on the stiffness's and the ultimate load capacities of the composite beams is presented; a study which has shown the vital effects of these parameters.

2. Finite Element Analysis –ANSYS Model:

2.1. Definition:

The commercial finite element analysis package ANSYS (16) (Analysis System version 5.4) was set up - with its parameters calibrated – and used in the analysis of the present reinforced concrete composite system with embedded precast prestressed concrete prisms. The program has the capacity of solving linear and nonlinear problems including the effect of cracking, crushing, shrinkage and creep of concrete, yield of reinforcement, bond-slip between the steel rebars and the surrounding concrete medium, and temperature changes, with about 165 different elements. Three types of finite elements modeling are used for the present reinforced concrete composite structural system containing embedded precast prestressed concrete prisms as given later on.

2.2. Material nonlinearities:

Nonlinearity properties; namely cracking and crushing of concrete in tension and compression respectively and yield of steel are taken into account through ANSYS operations.

2.3. Element types:

2.3.1. Concrete:

The 8-node isoparametric linear brick element SOLID65- with three translational degrees of freedom at each node shown in Figure-1 is used in the present work for modeling both the in-situ and the precast concretes (with the appropriate mechanical properties for each). This element is capable of plastic deformation, cracking in the three orthogonal directions, and crushing

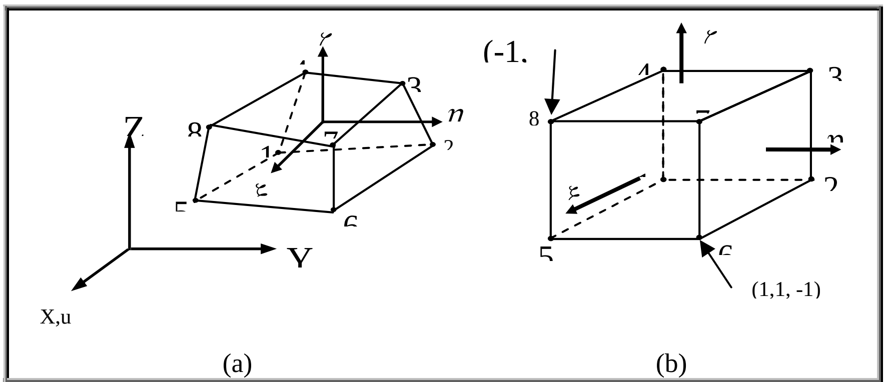


Figure (1) Brick element SOLID-65 with 8 nodes used for in-situ and precast concretes (a) global coordinate system, (b) local coordinate system.[16]

2.3.2 Nonprestressed steel reinforcing bars:

The reinforcements including the longitudinal bars and transverse stirrups in the cast-in-situ concrete are introduced into the brick SOLID65 element by assuming it smeared throughout the element. Any orientation of the steel rebars is permitted. Use of this approach is supported by the fine-meshing of the in-situ concrete, especially at locations of the reinforcing bars as recommended by the package (16).

2.3.3 Prestressed steel strands:

LINK 8 element has been used to model the prestressing steel strands that are aligned with the precast prestressed concrete prisms. This element –shown in Figure 2- is a two-noded three-dimensional axial element which is also capable of plastic deformation.

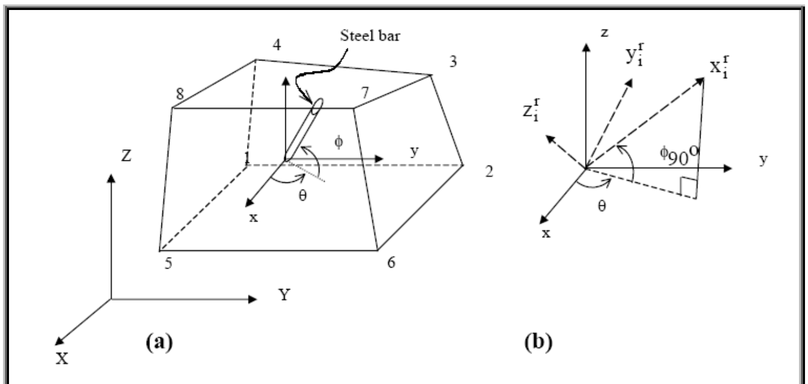


Figure (2) LINK8 axial element for the prestressing steel strands: [16]
(a) brick element SOLID65 coordinates x, y, z, with LINK8 element orientation,
(b) local coordinate system for LINK8 element

2.4. Meshing:

Meshes of the analyzed reinforced concrete composite beams with embedded precast prestressed concrete prisms are cubic elements (or ones of rectangular faces if the cubic discretization is impossible) are generated as recommended by the package.

2.5. Loads and boundary conditions:

To avoid crushing of the in-situ concrete under the effects of concentrated external loads and supports. reactions, the midspan applied loads and the end reactions are replaced by equivalent force systems of identical nodal forces at locations of the external forces and the reactions and in their vicinities as shown in Figure 3.

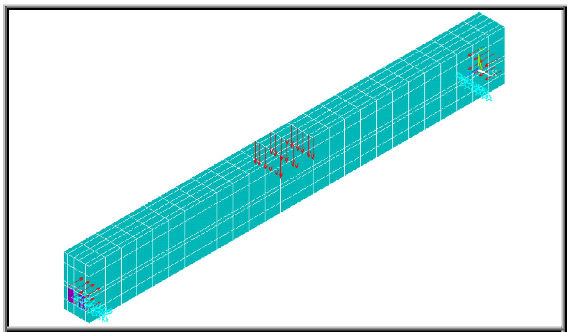


Figure (3) Typical finite element mesh pattern simulation of the applied concentrated load, the reactions, and the prestressing forces for each of the four analyzed composite beams.

2.6. Interfaces:

Bonds between the nonprestressed steel rebars and the surrounding in-situ concrete, the prestressing steel strands and the surrounding precast concrete, and surfaces of the in-situ and the precast concretes are all assumed to be perfect. Bond-slips at these specified surfaces are then not allowed. Accordingly, the defined contact locations are represented by participated nodes to avoid slip and the use of interface finite elements becomes unwarrantable.

3. Nonlinear solution algorithm:

The nonlinear equations of equilibrium are solved using an incremental-iterative technique under load procedure. The full Newton – Raphson method is used for the nonlinear solution algorithm and the displacement criterion is used as a convergence criterion, (16)

3.1. Numerical Integration:

Eight-node Gaussian rule for brick elements is used for numerical integration.

4. Applications:

4.1. Description of the analyzed composite beams:

The four reinforced concrete composite beams -with embedded precast prestressed concrete prisms- previously tested by Mawal(8) -are analyzed –in the present work- by the finite element method. All beams are rectangular in cross-section (with different cross-sectional dimensions), simply supported over 2400mm spans and loaded at their midspans. The four beams comprise precast prestressed concrete prisms(embedded at their bottoms to act as tension reinforcement), axially prestressed- at their centroids- by high strength prestressing steel strands, and running along their 2400mm spans.

They are also provided by bottom tensile and top compressive longitudinal nonprestressed deformed mild steel bars fixed at their locations by attached transverse reinforcement (stirrups) proportioned to resist diagonal tension. The four beams are different in numbers, size and locations of the embedded precast prestressed concrete prisms, numbers and diameters of the prestressing strands, and size, numbers and locations of the longitudinal –top and bottom- nonprestressed deformed mild-steel reinforcing bars. The nominal dimensions of the four analyzed composite beams, details of their embedded precast prestressed concrete prisms, prestress, and reinforcement with their loading scheme are shown in Figure 4.

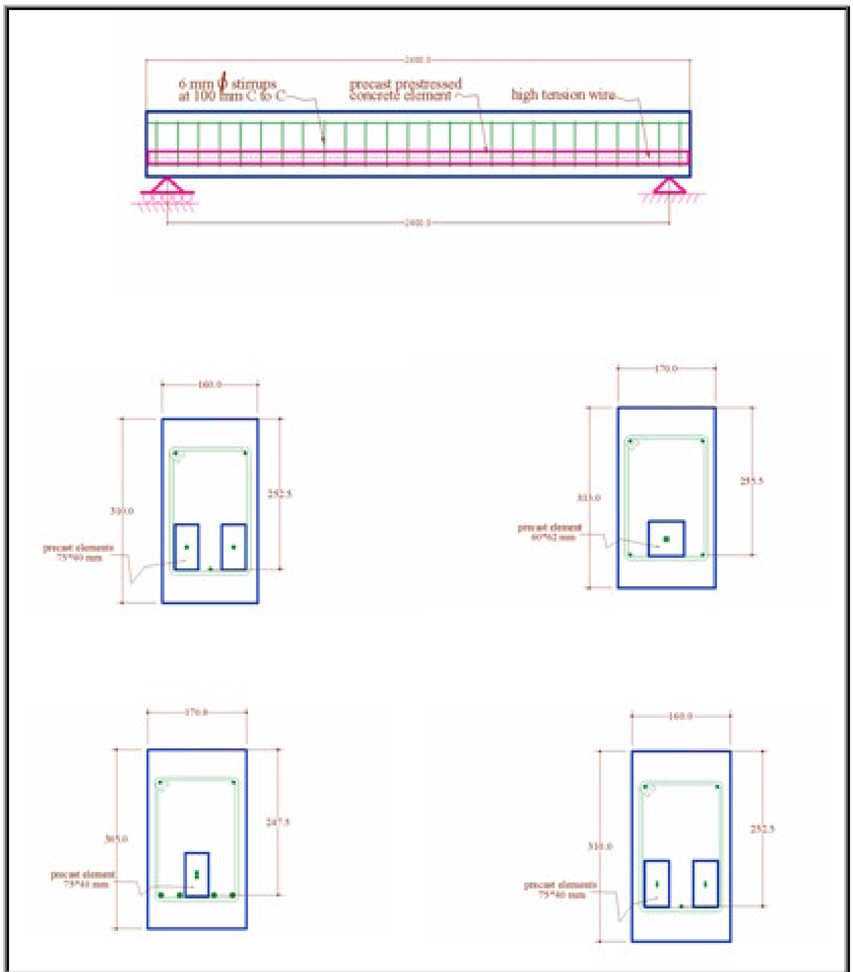


Figure (4) Detailed and loading scheme of the for analyzed reinforced concrete composite beams with embedded p.p.c. prisms, (a)longitudinal section, (b)cross-section.

The whole cross-sectional properties of the four analyzed composite beams with the cross-sectional areas of their prestressing strands and the tensile and compressive non-prestressed deformed mild steel bars are all given in Table1

Table (1) Sectional properties of the four analyzed reinforced concrete composite beams with embedded prestressed concrete prisms previously tested by Mawal(8).

	Beam E-1	**Beam F-1**	**Beam SB**	**Beam F-5**
Overall cross-sec. b*h (mm)	160*310	170*313	170*305	160*310
Effective depth;d (mm)	252.5	255.5	247.5	252.5
No. and size of p.p.c. prisms (mm)	2(40*75)	1(60*62)	1(40*75)	2(40*75)
No. and size of tensile non-prestressed steel rebars at bottom	1-? 6 mm	2-? 6 mm	4-?10 mm	1-? 6 mm
No. and size of comp. non-prestressed steel rebars at top	2-? 6 mm	2-? 6 mm	2-? 6 mm	2-? 6 mm
No. & size of prestressing steel strands	2-? 7 mm	4-? 5 mm	2-? 7 mm	4-? 5 mm
Stirrups (mm) c/c	? 6 @100	? 6 @100	? 6 @100	? 6 @100
Ars. Tensile (mm2)	28.27	56.54	314.16	28.27
Ars. Comp. (mm2)	56.54	56.54	56.54	56.54
Aps. (mm2)	76.96	78.54	76.96	78.54

4.2. Material properties of beams constituents:

The normal weight cast-in-situ concrete was obtained from a ready mix plant using 19mm (3/4in) aggregate maximum size; the precast concrete prisms were fabricated by a specialized firm using a 6.3mm (1/4in) maximum aggregate size.

The prestressing steel strands and the non-prestressed mild steel deformed bars of the used sizes(6mm and 10mm in diameter) all conformed with ASTM requirements(8).
The comprehensive material properties and parameters for the four defined constituents of each of the four composite beams analyzed in the present study are all given in Table 2.

Table (2) Material properties of the analyzed supported reinforced concrete composite beams with embedded prestressed concrete prisms previously tested by Mawal(8).

			Beam E-1	Beam F-1	Beam SB	Beam F-5
Cast-in-situ concrete	E_c	Young Modulus (GPa)	25.05	21.95	24.2	20.18
	f_c'	Comp. strength (MPa)	28.4	21.8	26.5	19.6
	υ_c	Poisson's Ratio *	0.15	0.15	0.15	0.15
	β_o β_c	Shear transfer Coeff. *	0.1 0.99	0.1 0.99	0.1 0.99	0.1 0.99
	f_t	Tensile strength (MPa) **	2.66	2.33	2.57	2.21
Precast prestressed concrete	E_{pc}	Young Modulus (GPa)	32.9	34.54	30.1	32.9
	f_{pc}'	Comp. strength (MPa)	49	54	41	49
	υ_{pc}	Poisson's Ratio *	0.2	0.2	0.2	0.2
	β_o β_c	Shear transfer Coeff. *	0.1 0.99	0.1 0.99	0.1 0.99	0.1 0.99
	f_{pt}	Tensile strength (MPa) **	3.5	3.67	3.2	3.5
Steel non-prestressed rebars	E_s	Modulus of Elasticity (GPa)*	200	210	210	210
	f_y	Yield Stress (MPa)	277.5	277.5	294.5 277.5 *****	277.5
	f_u	Ultimate Stress (MPa)	416	416	394.5 416 *****	416
	υ_s	Poisson's Ratio *	0.3	0.3	0.3	0.3
Steel prestressing strands	E_{ps}	Modulus of Elasticity (GPa)*	200	210	210	210
	f_{py}	Yield Stress (MPa)	1588	1588	1588	1588
	f_{pu}	Ultimate Stress (MPa)	1734	1618	1734	1618
	f_{pe}	a)****	382	550	662.68	275
	υ_{ps}	Poisson's Ratio *	0.3	0.3	0.3	0.3

* Assumed value
** ft =0.5*(fc')^0.5
*** fpt =0.5*(fpc')^0.5
**** fpe = (effective prest. Force per prism/Aps)
***** First numbers and second numbers (for each of the two marked properties of the nonprestressed rebars) are for 10mm and 6mm diameters respectively.

4.3. Finite Element Idealization of Studied Composite Beams:

With reference to Figure 3, which gives a general view of typical analysis of composite beams, each of the four beams is divided to certain numbers of the three specified finite elements of ANSYS program; SOLID65 with smeared reinforcement for in-situ reinforced concrete, SOLID65 without smeared reinforcement (with material properties different from those of the prism elements) prestressing steel strands detailed information concerning the total number of nodes and elements, in addition to the number of each of the three specified types of elements in cross-sectional, span-wize(axial) and comprehensive volumetric dimensions for each of the four analyzed composite beams are given by Table3.
It is worth mentioning – with reference to Table3 that in the case of two or more contacting prestressing steel strands within one precast concrete prism, one LINK8 element in cross-section(of properties equal to the accumulating properties of the abutting strands) is used to present them altogether.
The number of LINK8 elements in cross-section for a specified precast concrete prisms is equal to the number of axial prestressing steel strands, aligned within that prism, thus reflecting the necessity of representing each

strand by a separate axial element even through two or more strands are abutting.

As stated previously, a concentrated applied load and end reactions are represented by equivalent system of certain numbers of identical nodal forces – Figure3- to avoid crushing of concrete under effect of point loads. Those numbers of nodal forces simulating the mid-span concentrated loads and end reactions – in addition to numbers of sets of constants specifying the smeared nonprestressed reinforcement in SOLID65 elements analogous to the in-situ reinforced concrete (16) – are given in Table 4 for each of the four analyzed composite beams

Table (3) Media divisions and finite element meshing of the four analyzed reinforced concrete composite beams with embedded precast prestressed concrete prisms previously tested by Mawal(8).

Media	ANSYS Modeling Element (ref.16)		Beam Designation											
			E-1			F-1			SB			F-5		
			No. of Elements			No. of Elements			No. of Elements			No. of Elements		
	Designation	Type	in cross-sec.	in axis	total	in cross-sec.	in axis	total	in cross-sec.	in axis	total	in cross-sec.	in axis	total
Cast in-situ reinforced concrete	SOLID 65	8-node brick ele. with smeared reinf.	21	26	546	22	26	572	22	26	572	21	26	546
Precast concrete	SOLID 65	8-nodes brick ele. without smeared reinf.	2	26	52	1	26	26	1	26	26	2	26	52
Prestressing steel strands	LINK 8	2-node spatial axial element	2	26	52	4	26	104	2	26	52	4	26	104
Comprehensive Number of Elements for Each Beam (comprising the 3 specified element types)			25	26	650	27	26	702	25	26	650	27	26	702
Total Number of Nodes for Each Elemen			972			1026			972			1026		

Table (4) Idelization of applied loads and end reactions, and SOLID65* smeared reinforcement properties for the four composite beams.

	Beam Designation			
	E-1	F-1	SB	F-5
No. of nodal loads equivalent to a midspan applied load	18	30	30	30
No. of nodal loads equivalent to an end reaction	9	15	15	15
No. of sets of constants specifying smeared reinf.*	8	5	7	7

*Properties of SOLID65 element with smeared reinforcement are as given by ANSYS program (16)

4.4. Presentation and Discussion of Results:

To get deflection values for different values of the applied mid-span concentrated load from the present finite element model for each of the four simply supported reinforced concrete composite beams comprizing embedded prestressed precast concrete prisms, the prestressing force of each strand must first be incrementally applied followed by the incremental application of the external load and the corresponding deflection values are than calculated. Load-deflection curves thus obtained from the present mathematical models of the four composite beams with the corresponding curves obtained by Mawal's(8) specimen tests are shown in Figure 5, from which the following main remarks are established:

it can be noticed from Figure 5-a (for beam E-1) that both the theoretical and the experimental curves start and continue close to each other till end of the two third of the linear elastic (precracking) stage. Within the last third of that stage the numerical model starts to give lower values of deflections for the same load values (i.e. higher stiffness) than the experimental specimen. Then at the onset of the first cracking noticeable lowering of stiffness in the numerical model is recorded. Finally, curves of both the mathematical and the test models terminate at the same load value but with some difference in deflection values owing to the unclearenss of the deflection data at failure in Mawals' test (8).

Good agreement between the theoretical and the experimental load-deflection curves of beam F-1 (shown in Figure5-b) is obtained with no distinct secession point between the precracking and the post-cracking stages. A smaller difference in deflection values at the post-cracking stage of the two curves is obtained in comparison with the case of beam E-1. While the two curves of beam F-1 terminate at the same load level, a noticeable difference in the accompanying deflection values is recorded but less than the corresponding deflection difference of beam E-1.

With reference to Figure (5-c), the difference in the early stage between the behaviors of the finite element model and the experimental specimen for beam SB is approximately equal to the corresponding difference for beam E-1; The behavior of the numerical model of beam SB will then approach the test specimen behavior until the two curves intersect twice. The two curves will then terminate with small difference in the load values due to the unclearness of the failure point in Mawal's test (8).

Figure 5-d illustrates the close behavior of the numerical and the test models relevant to beam F-5 in the initial linear (precracking) stage, followed by the slight divergence between them which increase after exceeding 80% of the ultimate load where values of deflection for the two modules are identical.

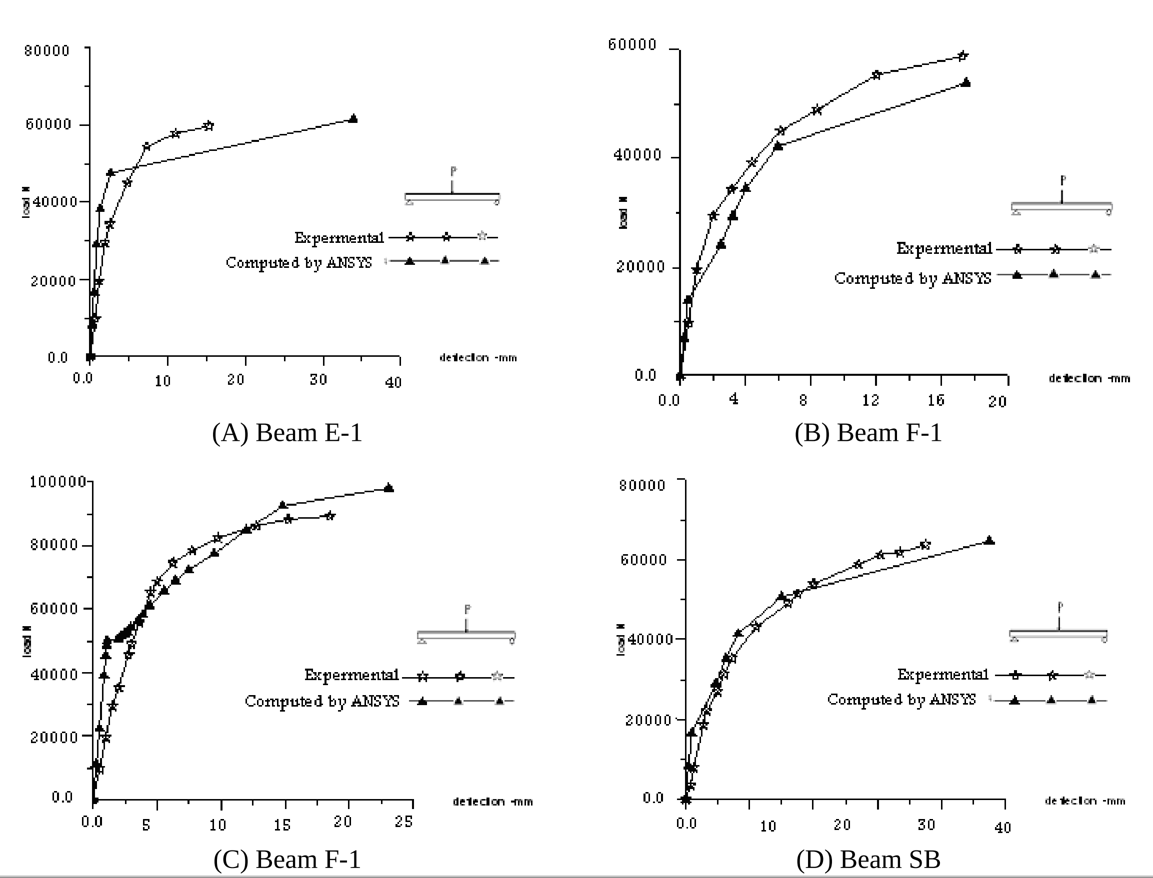


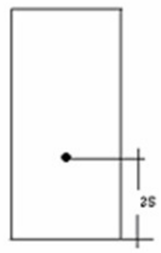
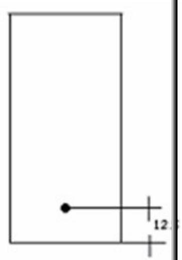
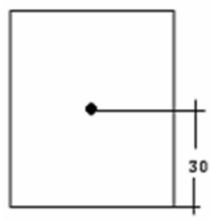
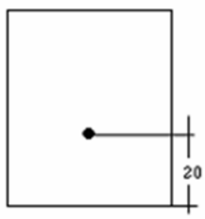
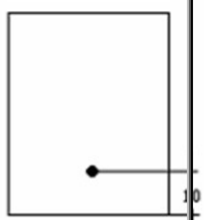
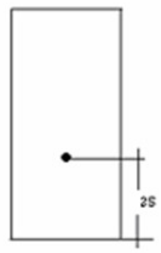
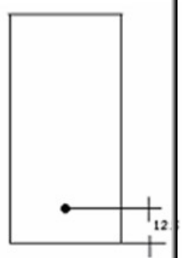
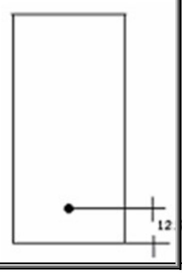
Figure (5) : Load deflection curves obtained by finite element model of the present work, and the test specimens of Mawal(8) for the four reinforced concrete composite beams.

5. Parametric Study:

5.1 Effect of positions of the prestressing steel strands within precast concrete prisms:

To investigates the effects on stiffness and ultimate resistance of varying positions of the axially aligned prestressing steel strands-and hence the resultant prestressing forces-within their precast concrete prisms – of the different specified cross-sectional dimensions-embedded in the four simply supported reinforced concrete composite beams, a comprehensive study of that parameter effect based on the present finite element model is set up, the outline of this investigation (given in Table5) comprises three specified cross-sectional locations of the resultant prestressing force within each of the four types of the precast concrete prisms.

Table (5) Specified varying locations of the resultant prestressing force within their precast concrete examined by the present finite element model for the four composite beams

			Locations of Resultant Prestressing Force within its Precast Concrete Prism		
			Original location	2nd location	3rd location
Beam Designation & Specification	E-1	2 precast prisms 1-?7mm strands per prism			
	F-1	1 precast prisms 4-?5mm strands per prism			
	SB	1 precast prisms 2-?7mm strands per prism			
	F-5	2 precast prisms 2-?5mm strands per prism			

Changing location of the resultant prestressing force within each precast concrete prism requires in the present finite element model-redistribution of the initial prestressing force over the SOLID65 brick elements of the precast concrete prism within its cross-section.

Load-deflection curves emanating from program of this parametric investigation (given by table5), and composed on the bases of the present finite element model for the four simply supported reinforced concrete composite beams are shown in Figure6 from which it is observed –in general- that the increase in the resultant prestressing forces eccentricities within their precast prisms lead to increases in the stiffnesses and ultimate resistances of their global composite beams. Values of these increases are incongruous depending on the cross-sectional curves of the prestressing steel relative to the cross-sectional area of their containing precast prisms, and on the cross-sectional areas of the precast prisms relative to the overall cross-sectional areas of their containing composite beams. As those relative cross-sectional areas increase, values of the defined increases in stiffnesses and ultimate resistance increase accordingly. The upper bound of the eccentricity value is controlled by the minmum. required precast concrete cover of the prestressing strands. Detailed remarks on that parametric study are presented later in the main conclusions.

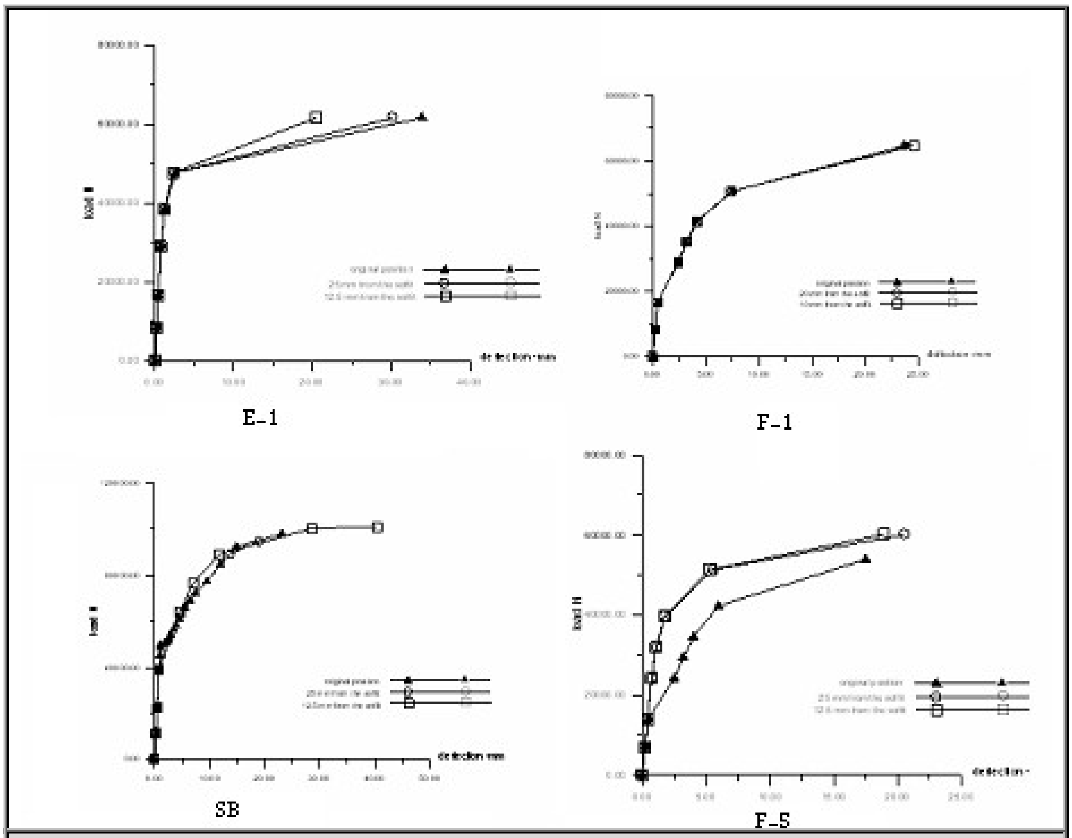
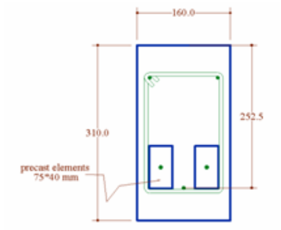
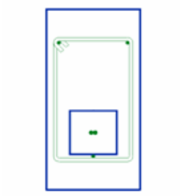
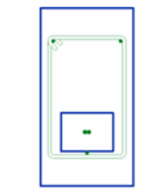
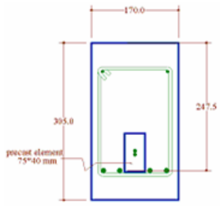
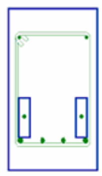
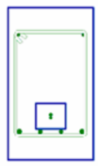
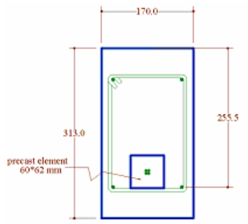
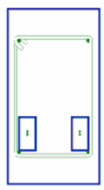
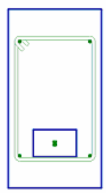
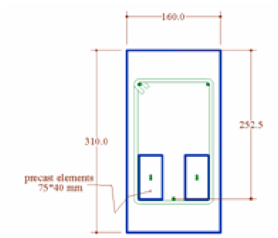
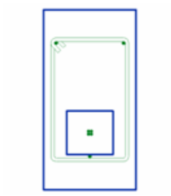
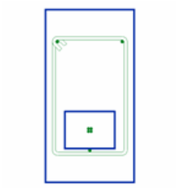


Figure (6) Load-deflection curves given by the present finite element model for the different locations of resultant prestressing forces specified in Table5 for each of the four composite beams.

2-Effect of Division numbers and cross-sectional aspect ratio of the precast Concrete Prisms:

In order to specify the best geometric state (comprising numbers and cross-sectional aspect ratios of divisons) of the precast prestressed concrete prisms with keeping total cross-sectional areas of the precast prisms and of the prestressing steel strands unchanged-which are embedded at bottoms of the four simply supported reinforced concrete composite beams (as shown in Figure4); three specified geometric states of the two geometric parameters defined above-for the precast prisms are introduced for each of the four composite beams, producing twelve different simply supported reinforced concrete composite beams with embedded precast prestressed concrete prisms. The twelve composite beams are then analyzed by the present finite element model to examine the effect of those geometric parameters; outline of this parametric investigation on the twelve composite beams is given by Table6.

Table (6) Specified varying geometric states for divisions of the prestressed concrete prisms embedded in the four analyzed reinforced concrete composite beams.					
			Locations of Resultant Prestressing Force within its Precast Concrete Prism		
			Original location	2nd location	3rd location
Beam Designation & Specification	E-1	Apc* = 6000	 2(40*75)	 1(80*75)	 1(90*66.7)
	F-1	Apc* = 3000	 1(40*75)	 2(20*75)	 1(50*60)
	SB	Apc* = 3720	 1(62*60)	 2(31*60)	 1(80*46.5)
	F-5	Apc* = 6000	 2(40*75)	 1(80*75)	 1(90*66.7)

*Apc is the total cross-sectional area of the precast concrete prisms in a composite beam (mm2)

Load-Deflection curves emanating from program of this parametric investigation (given by Table 6), and composed on the bases of the present finite element model for the four simply supported reinforced concrete composite beams are shown in Figure 7. Inspection of the four graphs of this figure shows that for composite beams E-1 and F-5- for which the total cross-sectional areas of the precast concrete prisms; Apc are relatively large (6000 mm2 for each)-, the slight change of the cross-sectional aspect ratio of those prisms without changing numbers of divisions

(1st and 2nd alternative states in accordance with Table 6) has a negligible effect on beam stiffness, while the change in the number of divisions with keeping the overall cross-sectional aspect ratio unchanged (original and 1st alternative states in accordance with Table 6) produces a significant effect. In the case of the composite beams F-1 and SB for which the total cross-sectional areas of the precast concrete prisms; Aps are relatively small (3000 and 3720 mm2 respectively), that fact -describing the effects of the two defined geometric parameters- reverses.

In general, the specified effects of the two defined geometric parameters are inspected only in post-cracking stage. In the linear (precracking) stage none of the two defined geometric parameter has any measurable effect.

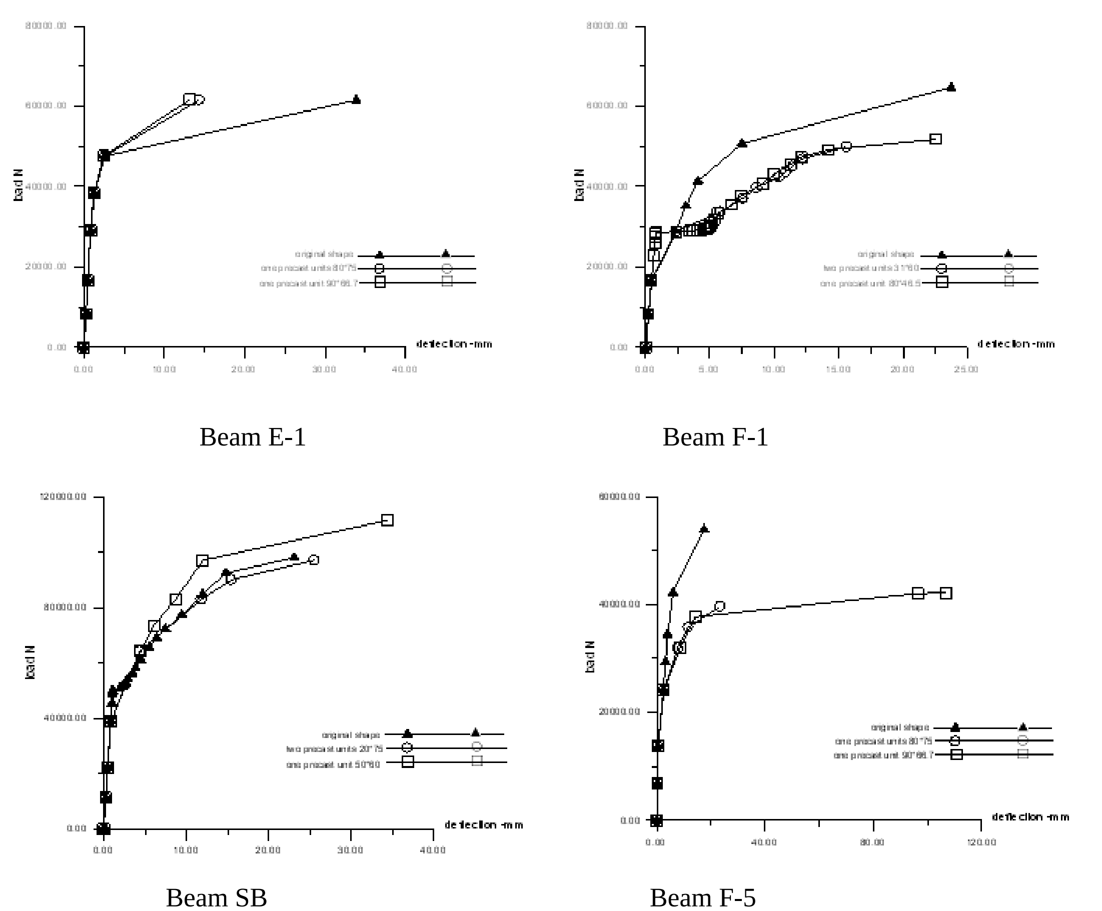


Figure (٧) Load-deflection curves given by the present finite element model for the different geometric states described in Table 7 of the prestressed concrete prisms embedded in the four composite beams.

6. Conclusions:

The following points may be concluded from the present study:

1- The present three dimensional nonlinear finite element model by the computer program (ANSYS 5.4) is suitable to predict the flexural behavior of simply supported reinforced concrete composite beams with embedded precast prestressed concrete prisms. Numerical results show that the collapse loads given by the present finite element model are in good agreement with those obtained in the previous experimental work (8).

2- In particular, modeling both the in-situ reinforced concrete and the precast prestressed concrete prisms by the eight-nodes brick elements SOLID65 using smeared steel reinforcement in the elements of the in-situ concrete only and introducing the appropriate concrete properties in each of the two types of those brick elements with the assumption of full interlocking between the two concrete media, accompanied by modeling the prestressing steel strands by the two-nodded axial spatial element LINK8 give good accuracy in comparison with experimental results of Mawal's specimens(8).

3- Using of precast prestressed prisms in simple composite beams improves their flexural stiffness and ability to sustain more live loads.

4- The two main parameters affecting the flexural behavior of reinforced concrete composite beams with embedded precast prestressed concrete prisms are the eccentricity of the centrodial axis of the prestressing steel strands within their containing precast concrete prism and the geometric state of the precast prestressed concrete prism (comprising the number and cross-sectional aspect ratio of its divisions). However, by applying the present finite element model, it is observed that their significant effect is restricted to the post-cracking region of the flexural performance of the defined composite beams. They have negligible effect on such composite beams within the linear (precracking) stage of their flexural performance. Details and amounts of these two parametric effects are given here under concluding terms 5,6 and 7.

5- Concerning effect of the eccentricity of the prestressing steel strands – within their containing precast concrete – prisms on the flexural stiffness and ultimate resistance of the whole simply supported composite beam in the inelastic (post-cracking) region, it is observed by appling the present finite element model that the incessant increase in the eccentricity of a resultant prestressing force leads to significant monotonous increases in both the flexural stiffness and ultimate resistance of the whole composite beam. Values of those increases in flexural properties depend directly on the cross-sectional areas of the precast prisms relative to the overall cross-sectional areas of their containing composite beams, and on the cross-sectional areas of the prestressing steel strands relative to the cross-sectional areas of their containing precast prisms. The higher the relative first or second defined cross-sectional areas, the higher are percentages of increase in the corresponding flexural stiffness and ultimate load capacity of the composite beam. The percentage of increase in the ultimate resistance due to the specified variation in that parameter is within the range 5-11%for the four composite beams.

6- Based on the present finite element model, effect of the number of divisions of the precast prestressed media (of constant cross-sectional area) on the flexural stiffness and ultimate resistance of the specified composite beams depends mainly on the total cross-sectional area of the precast prestressed concrete prism (within one composite beam) relative to the whole cross sectional area of the containing composite beam. The higher this relative cross-sectional area in a composite beam of this type, the higher is the effect of the number of the defined divisions on the flexural stiffness and ultimate resistance of that beam. The percentage of difference in the ultimate resistance due to the specified variations in that parameter is within the range 2-15.6% for the four composite beams.

7- Effect of the cross-sectional aspect ratio of the precast prestressed concrete prism of constant cross-sectional area (as investigated by applying the present finite element model) on the flexural behavior of the reinforced concrete composite beam containing that precast prism, also depends mainly on the relative cross-sectional area of the precast presstressed concrete prism defined in the previous point, but in the converse (opposite) direction. The higher this relative cross-sectional area in a composite beam of this type, the lower is the effect of the defined cross-sectional aspect ratio on the flexural stiffness and ultimate resistance of that composite beam. The percentage of difference in the ultimate resistance due to the specified variations in that parameter is within the range 1.7-19% for the four composite beams.

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سلوك الروافد المركبة الخرسانية المسلحة المتضمنة موشورات خرسانية مسبقة الجهد باستخدام التحليل اللاخطي بالعناصر المحددة

د. ليث خالد الحديثي
مدرس
كلية الهندسة/جامعة النهرين

حمزة صادق عبد الكريم
ماجستير هندسة مدنية

الخلاصة:

يعنى البحث الموصوف أدناه بدراسة نظرية لسلوك الانحناء لروافد مركبة بسيطة الارتكاز تتكون من موشورات خرسانية مسبقة الصب و الجهد تعمل كتسليح شد في الخرسانة المسلحة، بانشاء نموذج لاخطي ثلاثي الابعاد بالعناصر المحددة.

تم استخدلم العناصر الطابوقية الأيزوبارامترية ثمانية العقد- بوجود و بغياب حديد التسليح المفروش – لتشكيل الوسط الخرساني المسلح و الموشورات الخرسانية مسبقة الصب على التوالي، باستخدام خصائص المواد المحددة مع الاخذ بنظر الاعتبار ظاهرتي تشقق الشد و انسحاق الضغط لكل من نوعي الخرسانة المستخدمين. أما بالنسبة للحبال الحديدية مسبقة الاجهاد فقد تم تمثيلها باستخدام العناصر المحورية ثلاثية الابعاد القادرة على التشوة اللدن في مرحلة ما بعد الخضوع. تم افتراض ترابط تام لكل سطوح التماس الخرسانية – الخرسانية، و الحديدية- الخرسانية.

تم استخدام برنامج العناصر المحددة ANSYS – مع عنصرية المؤهلين الطابوقي و المحوري – لقياس سلوك الحمل – الهطول لأربعة عتبات نموذجية بسيطة الارتكاز تستخدم النظام المركب المذكور اعلاه ، و تختلف فيما بينها بالأبعاد الاجمالية للمقطع العرضي و المساحات النسبية لمقاطع الموشورات مسبقة الصب ، للحبال مسبقة الاجهاد ، و لقضبان التسليح الاعتيادية . كما تمت مقارنة هذا السلوك مع سلوك اربعة نماذج عملية مناظرة للنماذج الرياضية تم فحصها مختبريا في بحث سابق للتحقق من دقة نموذج العناصر المحددة في المرحلة الخطية و مرحلة مابعد التشقق.

تم اجراء دراسة مقارنة تتضمن تاثيرات اللاتمركز النسبي للحبال الحديدية المسبقة الاجهاد و لحالة الهندسية الشكلية geometric للموشورات الخرسانية مسبقة الصب و الاجهاد على سلوك الهطول لذلك النظام الانشائي المركب لحساب تاثيرات العاملين المذكورين على الصلادة stiffness و المقاومة القصوى لأثبات دورهما الاكبر بعد التشقق الذي يعتمد على الكميات النسبية للموشورات مسبقة الصب و للحبال مسبقة الاجهاد.

اثبتت النتائج الدقيقة للنموذج الحالي بالعناصر المحددة فعالية و موثوقية هذا النموذج في تحليل هذا النوع من الانظمة الانشائية المركبة لتعطي بذلك دفعا باتجاه توسيع تطبيق و استخدام النموذج الحالي في هذا المضمار.