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The behavior of Reinforced Concrete Planted Columns Supported on Reinforced Concrete Beams

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Abstract

Changing columns' positions or directions through different floor levels may cause many problems if not taken into design considerations. Unfortunately, there are no specifications or design requirements in the different codes of practice to design beams that have planted columns. This theoretical investigation aims to specify the planted column-beam connection's behavior, considering the beam width, the direction of the column, its dimensions, and shear reinforcement distributions. Therefore, a three-dimensional nonlinear finite element analysis was carried out for 17 models sorted into 5 groups. It was observed that the longer side of the planted column direction, which is perpendicular to the beam span, had better behavior in failure load and deflection than it was parallel to the beam span. Also, the planted column length preferred to be taken the same as the beam width for better behavior.

Keywords - *supported beams; planted columns; shear stresses; bending stresses.*

I. INTRODUCTION

Columns are the most critical compression members which transmit loads from the top level to the lowers and then to the soil passing through the foundations. A planted column is a vertical compression member supported on a non-axial bearing member such as slabs or beams to answer the structural requirements without sacrificing interior and architectural needs. Unfortunately, there are not many studies about the behavior of planted columns and the supported beam.

Hansapinyo et al. (2003) [1] have an experimental study on thirteen reinforced concrete beams with square and rectangular cross-sections to study ultimate capacity under bi-axial shear loading and the ultimate bi-axial shear capacities of concrete and shear reinforcement were defined separately. The estimations of the bi-axial shear capacity of the shear reinforcement for rectangular sections gave the value in the rage of 0.88-1.27 of the tests. Also, the ellipse formula was underestimated bi-axial shear capacity. While it was overestimated the bi-axial shear capacity of shear reinforcement of specimens with a rectangular section in which a model to calculate shear reinforcement capacity is formulated based on diagonal crack configuration. Waryosh et al. (2014) [2] had tested four reinforced concrete beams with variation in shear reinforcement ratio, and the ellipse interaction relation results seem to underestimate the bi-axial shear capacity of concrete about (119 to 188%) and (43 to 50%) according to ACI and JSCE design codes respectively, while overestimating the bi-axial shear capacity of shear reinforcement of reinforced concrete members with rectangular cross-sections by the range of (21) to (6) % and (25) to (11) % according to ACI and JSCE code, respectively.

Chaisomphob et al. (2003) [3] made an experimental study on four reinforced concrete members to study the mode of failure and failure load of a reinforced concrete beam with a rectangular cross-section under combined bi-axial shear load accompanied with a torsional moment. The results showed that as the torsional moment increased to about 69%, the bi-axial shear capacity decreased to about 12% to 39% based on the ratio of bi-axial shears.

Finite Element Methods in the reinforced concrete beams analysis has become a very useful and handy tool in modern times due to the emergence of powerful computers. The use of Finite Element Analysis is high-speed and economical as compared to laboratory testing.

A. Objective

This theoretical investigation's main goal is to study the load capacity and deflection behavior of planted columns supported on beams that have been tested in the laboratory. Accordingly, to achieve these objectives, seventeen finite element models were divided into five groups.

B. Analytical program

This study's analytical program began with the element types, model details, and models' grouping. A nonlinear finite element model (ANSYS 14package) [4] was used to closely foretell the behavior of the reinforced concrete beam carrying a planted column.

a). Elements types

1). The concrete element

Concrete in compression: the idealized stress-strain curve based on the Egyptian Code of Practice (ECP 203-07) [5] can represent the actual behavior of concrete in compression. It consists of a parabola up to a strain of 0.002 and a straight horizontal line up to a strain of 0.003.

SOLID65, the solid element used to model the concrete has eight nodes with three degrees of freedom at each node and translations in the nodal x, y, and z directions. This element can predict cracking in three orthogonal directions, crushing, creep, and plastic deformation. The "SOLID65" element requires linear and multi-linear isotropic material properties to model the concrete. "Willam et al. (1974) [6] use the multi-linear isotropic material model to define the failure of the concrete and "ACI code, MacGregor (2011) [7]" use the multi-linear isotropic compressive stress-strain curve in the concrete model according to.

The model can be foretelling the concrete's failure, as shown in Figure1, where cracking and crushing failure modes were taken into consideration.

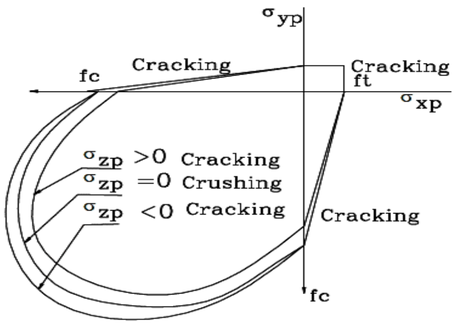

Figure1: the surface of the concrete failure

When the principal tensile stress in any direction lies outside the failure surface, cracking occurs in the concrete element. After cracking, Young's modulus of the concrete element was set to zero parallel to the principal tensile stress direction. When all principal stresses are compressive and lie outside the failure surface, the crushing occurs. After that, Young's modulus again was set to zero but in all directions, and the element effectively disappears. Material model in “ANSYS (14)”[4] requires defining the properties of concrete as shown in Table (1), also multi-linear isotropic stress-strain curve shown in Table (2).

Table1:Materials properties for concrete

Property	E_c (N/mm^2)	σ_{cu} (N/mm^2)	σ_{tu} (N/mm^2)	υ	βr (opened crack)	βr (closed crack)
Model	22000	25	3	0.2	0.2	1.0

Table2: Multi-linear isotropic stress-strain curve for the concrete curve used in modeling

Point	1	2	3	4	5	6	7	8	9	10
Stress	8.36	10.0	12.0	14.0	16.0	18.0	20.00	22.0	25.0	25.0
Strain $*10^{-6}$	380	470	580	690	820	960	1310	1350	2520	2500

2). The reinforcement element

The mechanical properties of steel are familiar and understood. Reinforcement steel is a homogeneous material and usually has the same yield strength in tension and compression. In the present study, reinforcing steel is modeled as a bilinear elastoplastic material, essentially using the idealized stress-strain curve.

A 3-D element (LINK180) was used to model the steel. LINK180 is a uniaxial tension-compression element with three degrees of freedom at each node, translations in the nodal x, y, and z directions. Inhinged joint structure, no bending of the element is considered. The summary of material properties for the reinforcement steel is in Table (3).

Table3: Material properties for the reinforcement

Property	E_s (N/mm^2)	Elastic modulus	F_y (N/mm^2)	Y
Reinforcement	200000	0.0	360	0.30
Steel plates	200000	0.0	---	0.30

3). Steel plate's element

SOLID65 was used for the steel plates added at loading and supported points in the models to provide even stress distribution over the loading areas and prevent local failure of concrete at these points.

b). *Main Parameters*

The main parameters taken into consideration are:

1. Beambreadth (b).
2. Planted column's longer side direction according to the beam.
3. Vertical shear reinforcement. To study these parameters.

Five groups are assumed and shown in Table (4).

Group (G1): consisted of four models S1-S2-S3and S4. To study beam width effect on the connection between the planted column and supported beam, where the longer side of the column direction (t_c) is perpendicular to the beam span at mid-span, and the beam width is equal to the breadth of the supported beam (b) as shown in Figure (2).

Group (G2): consisted of four models S1-S2-S3and S4. To study the effect of the column's longer side direction effect, where the longer side of the column direction (t_c) is parallel to the beam span at mid-span and the beam width equal to the breadth of the beam (b), as shown in Figure (3).

Group (G3): consisted of four models S1-S2-S3 and S4. To study the effect of increasing shear reinforcement, where the dimensions and the reinforcement details are the same as (G1-S3), increasing the shear reinforcement (stirrups) distribution to ø 8 every 75 mm.

Group (G4): consisted of three models S1-S2 and S3. To study the beam width effect on the connection between the planted column and the supported beam, the longer side of the column direction (tc) is perpendicular to the beam span at mid-span with increasing beam dimension and reinforcement shown in Figure (4).

Group (G5): consisted of three models S1-S2 and S3. To study the effect of increasing shear reinforcement while column longer side direction is parallel to the beam span, where the dimensions and the reinforcement details are the same as (G4-S3) but with changing the shear reinforcement distribution Figure (5).

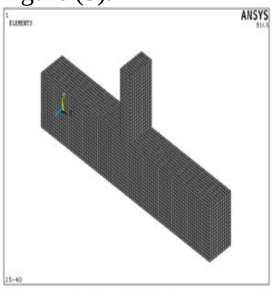

Figure 2: group (G1)

Figure 3: group (G2)

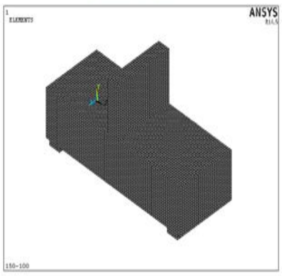

Figure 4: group (G4)

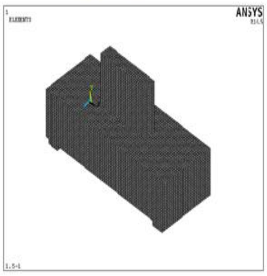

Figure 5: group (G5)

Table 1: models dimension and reinforcement details

* All the dimensions in mm.

c). *Model geometry and reinforcement details*

The typical specimen is a beam of 375*400*2000 mm with a planted column of 120*375*600 mm height which its location varied from one group to another. The typical dimensions and reinforcement details are drawn in Figure (6).

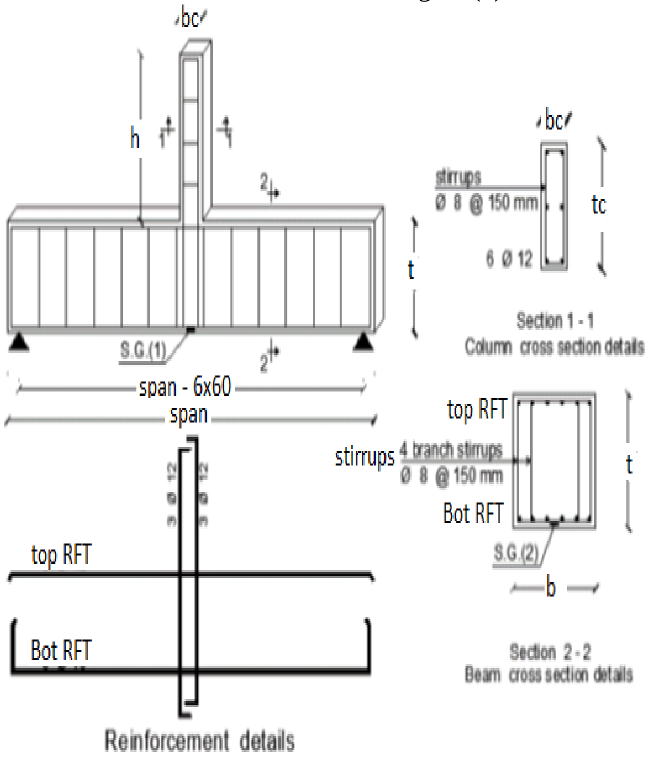

Figure6: The typical dimensions and reinforcement detailing

Model	Beam*						Column*		
	b (mm)	t (mm)	span	Top rft.**	Bot rft.**.	Shear reinforcement	t_c	b_c	h
G1-S1	125	400	2000	2y12	2y16	Y8@150mm	125	120	600
G1-S2	250	400	2000	4y12	4y16	Y8@150mm	250	120	600
G1-S3	375	400	2000	6y12	6y16	Y8@150mm	375	120	600
G1-S4	500	400	2000	8y12	8y16	Y8@150mm	500	120	600
G2-S1	125	400	2000	2y12	2y16	Y8@150mm	125	120	600
G2-S2	250	400	2000	4y12	4y16	Y8@150mm	250	120	600
G2-S3	375	400	2000	6y12	6y16	Y8@150mm	375	120	600
G2-S4	500	400	2000	8y12	8y16	Y8@150mm	500	120	600
G3-S1	375	400	2000	6y12	6y16	Y8@150mm	375	120	600
G3-S2	375	400	2000	6y12	6y16	Y8@125mm	375	120	600
G3-S3	375	400	2000	6y12	6y16	Y8@100mm	375	120	600
G3-S4	375	400	2000	6y12	6y16	Y8@75mm	375	120	600
G4-S1	1000	1000	4000	10y12	10y16	Y8@150mm	1000	300	1000
G4-S2	1200	1000	4000	12y12	12y16	Y8@125mm	1200	300	1000
G4-S3	1500	1000	4000	15y12	15y16	Y8@100mm	1500	300	1000
G5-S1	1500	1000	4000	15y12	15y16	Y8@150mm	1500	300	1000
G5-S2	1500	1000	4000	15y12	15y16	Y8@125mm	800	300	1000
G5-S3	1500	1000	4000	15y12	15y16	Y8@100mm	800	300	1000

** y represent steel grade 36/52

D. Finite Element Results, Analysis, and Discussions

The following factors were recorded for each model:

1. Failure load.
2. Maximum Deflection at mid-span of the supported beam.
3. Cracks propagations.

a). *Effect of changing of beam width*

Table (5) shows group (G1) failure load and its deflection value at the mid-span of the supported beam, and It can be concluded that the increase in beamwidth of the supported beam, which has a planted column perpendicular to the beam span, is linearly directly proportional to the failure with fewer deflection values as shown in Figures (7)&(8).

Table 2: Results of the group (G1)

Model Code	G1-S1	G1-S2	G1-S3	G1-S4
beam width/beam depth	0.3125	0.625	0.9375	1.25
Failure load (kN).	136.95	272.9	389.3	509.5
Max. deflection at mid-span in (mm)	10.19	9.96	9.31	9.10

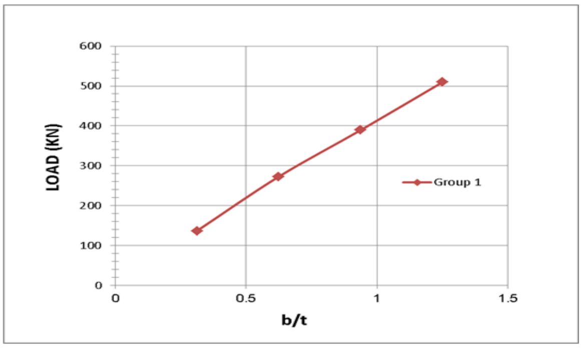

Figure 7: relation bet. load& b/t for G1

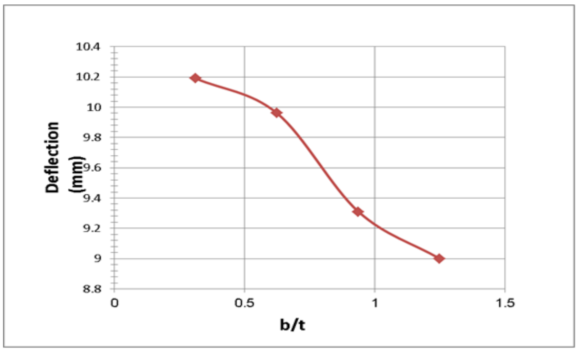

Figure 8: relations bet.deflection& b/t for G1

b) Effects of changing the column's longer side direction

Table (6) shows group (G2) failure load and its deflection at the middle of the supported beam, and It can be concluded that As increasing the beam width ratio which leads to an increase in the failure load but with less failure loads rate compared by group (1) as shown in Figure (11). Figures (9) & (10) show the relationship between the failure load and max deflections with (b/t). The relation is almost constant after the first point with absolutely the same deflection values at the failure load.

Table 3: Results of the group (G2)

Model Code	G2-S1	G2-S2	G2-S3	G2-S4
Beam width/Beam depth	0.3125	0.625	0.9375	1.25
Failure load (kN)	136.95	191.1	293.1	388.2
Maximum def.at mid-span in (mm)	10.19	6.764	6.80	6.857

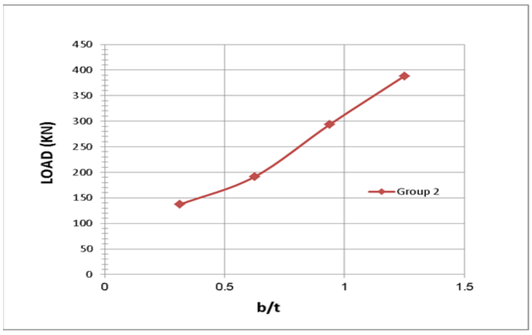

Figure 9: relation bet. load& b/t for G2

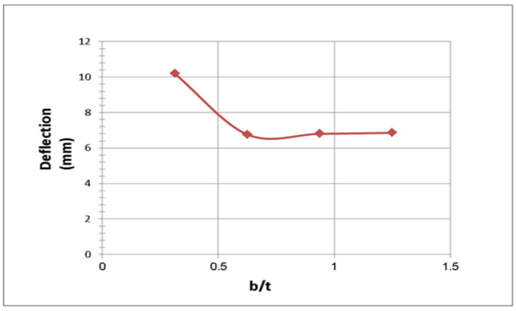

Figure 10: relation bet. deflection& b/t for G2

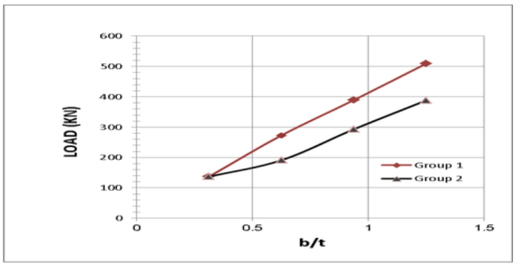

Figure 11: the relation between load & b/t for G1& G2

It can be concluded that the changing of column direction of the planted column in the group (2) to be the column length parallel to beam span at the centerline of the beam has a significant drop on the beam capacity with about 23.8% compared by Group (1). There is less propagation of cracks and fewer deflection values at the failure load than the Group models (1).

c).Effects of increasing shear reinforcement distribution

Table (7) shows group (G3) failure loads and their deflection values at the middle of the beam span. As increasing shear reinforcement distribution under the planted column on the load capacity of the beam where the column length is parallel to beam span, it can be concluded. Figure (12) shows that the relationship is most linear and inversely proportional to the beginning of the curve. As the spacing between the shear reinforcement was decreased under the planted column, that leads to an increase in the failure load until the value of spacing reaches 75mm, it was found less rate of increasing the failure load before for the previous points and the curve gets its way to be in a horizontal direction. Figure (13) shows the relationship between the deflections – spacing between shear reinforcement(S). The relation is almost linear, and the value of deflection increased with the increasing the beam capacity until reaching the value of spacing of 10mm. After this point, the deflection becomes all most constant.

Table 4: Results of the group (G3*)*

Model Code	G3-S1	G3-S2	G3-S3	G3-S4
Failure load (kN)	293.1	382.3	464.7	500.1
Max. deflection at Mid-span in (mm)	6.8	8.5	10.9	10.98

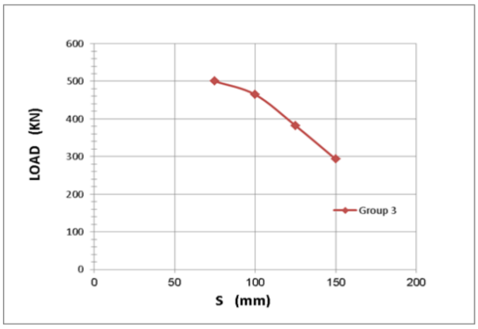

Figure 12: relation bet.load& stirrups spacing

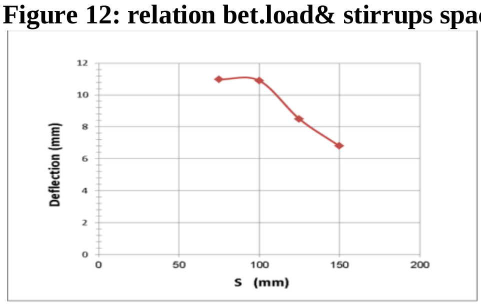

Figure 13: relation bet. deflection& spacing

It can be concluded that the changing of shear reinforcement distribution under the planted column with decreasing the spacing has a good enchainment and recovery of the beam capacity compared with regular spacing of shear reinforcement without decreasing it.

d). Effects of changing of beam width and column's longer side are perpendiculars to beam span(large scale beams)

Table (8) shows group (4) failure loads and their deflection values at the mid-span of the supported beam, and It can be concluded that the results in (Figure (14)show that the relationship is all most liner and directly proportional with beam width ratio, the behavior is almost the same as Group (G1).

Table 5: Results of the group (G4)

Model Code	G4-S1	G4-S2	G4-S3
beam width/beam depth	1	1.2	1.50
Failure load(kN).	1534	1843	2305
Maximum def.at mid-span in (mm)	4.321	4.31	4.36

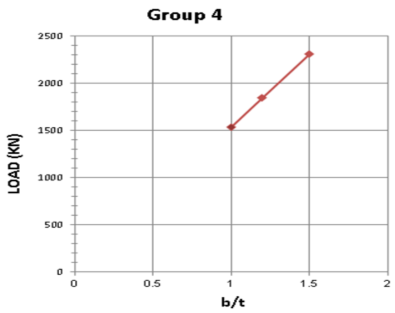

Figure 14: the relation between load & b/t for G4

e). ***Effects of changing of beam width and column's longer side are parallel to beam span (large scale beams)***

Table (9) shows group (5) the failure load and its deflection at the supported beam's middle. It can be concluded that, as the column's longer side change direction in model G5-S1 to make the column length parallel to beam span with (b/L) equal to 0.375, no effect was found in the failure load compared with model G4-S3, which have a column longer side in the other direction. Model G5-S2 has (b/L) equal to 0.20 had a drop in failure load by 30 % compared to models G4-S3and G5-S1. The model G5-S3 has (b/L) equal to 0.20 when the distribution of stirrups increased under the planted column, was found a full recovery of failure load for the beam. This indicates that the total areas of shear reinforcement under planted greatly affect the failure load.

Table 6: Results of the group (G5)

Model Code	G5-S1	G5-S2	G5-S3
Column length/Beam depth (b/L)	0.375	0.20	0.20
Failure load (kN)	2305	1603	2352

V. CONCLUSIONS

The following conclusions were drawn:

The case of the longer side of the planted column is perpendicular to beam span:

- The increasing beam width is linearly directly proportional to the supported beam's failure load, taking into consideration shear reinforcement specifications.

The planted column length preferred to be taken the same as the beam width for better behavior.

The case of the longer side of the planted column direction is parallel to the beam span:

- The increasing of the beam width is non-linearly proportional with the supported beam's failure load, which appeared to drop in failure load compared to the other direction of the planted column.

The case of the longer side of the planted column direction is parallel to the beam span as well as increasing the distribution of shear reinforcement under the planted column:

- Increasing the shear reinforcement distribution under the planted column indicates an enhancement in the load failure and functional recovery in the beam capacity.
- The decreasing of the distance between shear reinforcement is directly proportional to the failure load until shear reinforcement distribution of 100mm decreases more than this has no influence in increasing the failure load.
- If the longer side of the planted column direction is parallel to the beam span, it is advised to decrease the distance between the shear reinforcement (100 mm) with a distance less than the column length for the zone under the planted column.

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