Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (43) No. (4) October . 2021

Experimental and analytical study for Strengthening of Reinforced Concrete Columns at Intersection with Dropped Beams on One Side

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الملخص العربى :

كثيرا ما تكون الأعمدة الخرسانية المسلحه مصنوعة من خرسانة أقوى من الاسقف. ففي معظم الحالات يتم صب تقاطع العمود مع السقف بنفس خرسانة السقف .ونتيجة لذلك ، يجب أن تنتقل الأحمال في العمود عبر طبقة خرسانية ضعيفه قبل الوصول إلى العمود أسفل السقف .ويمكن التفكير في تقاطع العمود مع الكمره على "شطيرة" عمود ، مع طبقة خرسانية عالية القوة أعلى وأسفل طبقة خرسانية أقل قوة .هذا النوع من آلية نقل الحمل هو أمر بالغ الأهمية ويصف السلوك بأكمله .ولا تزال البحوث النظرية في نقاط القوة الفعالة في منطقة الربط بين العمود والكمرات الساقطة من اتجاه واحد ، غير موجودة .وأجريت تجارب على ثلاث عينات خرسانية مسلحه مصممة لتمثيل حالات تقاطع العمود مع الكمرات الساقطه ودراسة تقاطع العمود من أجل فحص قوة العمود عند التقاطع .وتشير النتائج إلى أن الربط مع نظام الكمرات الساقطه يزيد من اجهاد الخرسانه .وعند مقارنتها بالعينة التي لم يتم تدعيمها ، أظهرت العينة المدعمة زيادة في قوة الضغط الفعالة.

ABSTRACT:

Reinforced concrete columns are often constructed with stronger concrete than the floor slabs they support. In most cases, the slab is cast in a continuous pattern through the slab-column joint. As a result, loads in the column above the slab must travel through a weaker slab concrete layer before reaching the column below the slab. The column-slab junction can be thought of as a "sandwich" column, with high-strength concrete layered above and below a lower-strength concrete layer. This type of link's load-transmission mechanism is critical and it describes the whole behavior. Theoretical researches into the effective compressive strengths of the slab-column connection zone with dropped beams on one side are still lacking. Preliminary experiments were carried out on three reinforced concrete specimens designed to represent genuine column retention situations at the dropped beam and column junction in order to examine the column's compressive force at the intersection. The results suggest that enclosing the connection with a dropped beam system increases concrete strength. When compared to the specimen without reinforcement, the sample with its abeam-column reinforced steel connection region displayed an increase in effective compressive strength.

KEYWORDS: Reinforced concrete columns, Slab-column joint, Weaker slab concrete, High-strength concrete, Dropped beam, Finite element modeling, ABAQUS and column junction.

1. INTRODUCTION

Because of recent significant advancements in the field of concrete technology, great strength is now possible in the manufacture of concrete. High-strength concrete of 100 MPa is applied especially in high-rise buildings.

The strong compressive resistance characteristics of concrete materials can be more effectively utilized in structural column members with the application of high-strength concrete (HSC). The usage of HSC allows columns to be reduced as well as concrete resources to be saved, which also allows effective floor areas. Because HSC is not economical to be applied on large floor slabs, they are so typically designed and built using normal strength concrete (NSC), while the column members are coated with HCS materials, they are also the same.

From an economic point of view, this approach is quite useful, but it makes it tough to connect to the floor slab. To optimize the utilization of material resistance characteristics, slabs are constructed of normal strength concrete or lightweight concrete aggregate. For this reason, significantly different strength characteristics of concrete come into contact. The effect of the crossing of high strength concrete by weaker slab concrete is thus seen as a serious concern.

When the column and floor slab members have different concrete compressive strength grades, the provisions on current design in ACI [2] require an acceptable load transmission at the slab–column junctions via one of the following three techniques;

The first technique is to construct a floor close to the position of the column using the same concrete strength as the concrete column, for which a concrete from the column must be poured up to 600 mm from the surface of the column before hardening column concrete according to ACI or 500 mm according to CSA, And the concrete of the column is nicely incorporated with the concrete of the floor. For the column design, this approach is easy since the compression strength of the concrete column may be used for the column design. However, it demands a high degree of monitoring, precise coordination of concrete deliveries and the probable use of retardants, which necessarily reduces buildability.

In the second technique, the column member's axial strength is calculated through the floor system based on a lower concrete strength value with vertical dowels and spirals as required.

The third technique suggests the effective compressive strength (f′ce) that shall be used for the design of the member of the column. According to ACI and KCI, If the column's compressive strength (f′cc) is 1.4 times greater than that of the slabs in the compressive concrete slab (f′cj).

The current design codes (ACI 318-19; CSA A23.3-14 (2019)) includes a provision where the load transmission performance is guaranteed by the column if the upper/lower columns and slabs have different compressive strengths, as shown in Figure (1-a) (Urban and Gołdyn 2015). The ACI 318-19 indicates that if the column concrete's compressive strength is 1.4 times greater than that of the slabs compressive strength, the column concrete should be either extended by more than 600 mm beyond the column face, as illustrated in Figure (1-b), be strengthened in Figure (1-c) with vertical dowels or spirals, or adopt the effective compressive strength (f′ce).

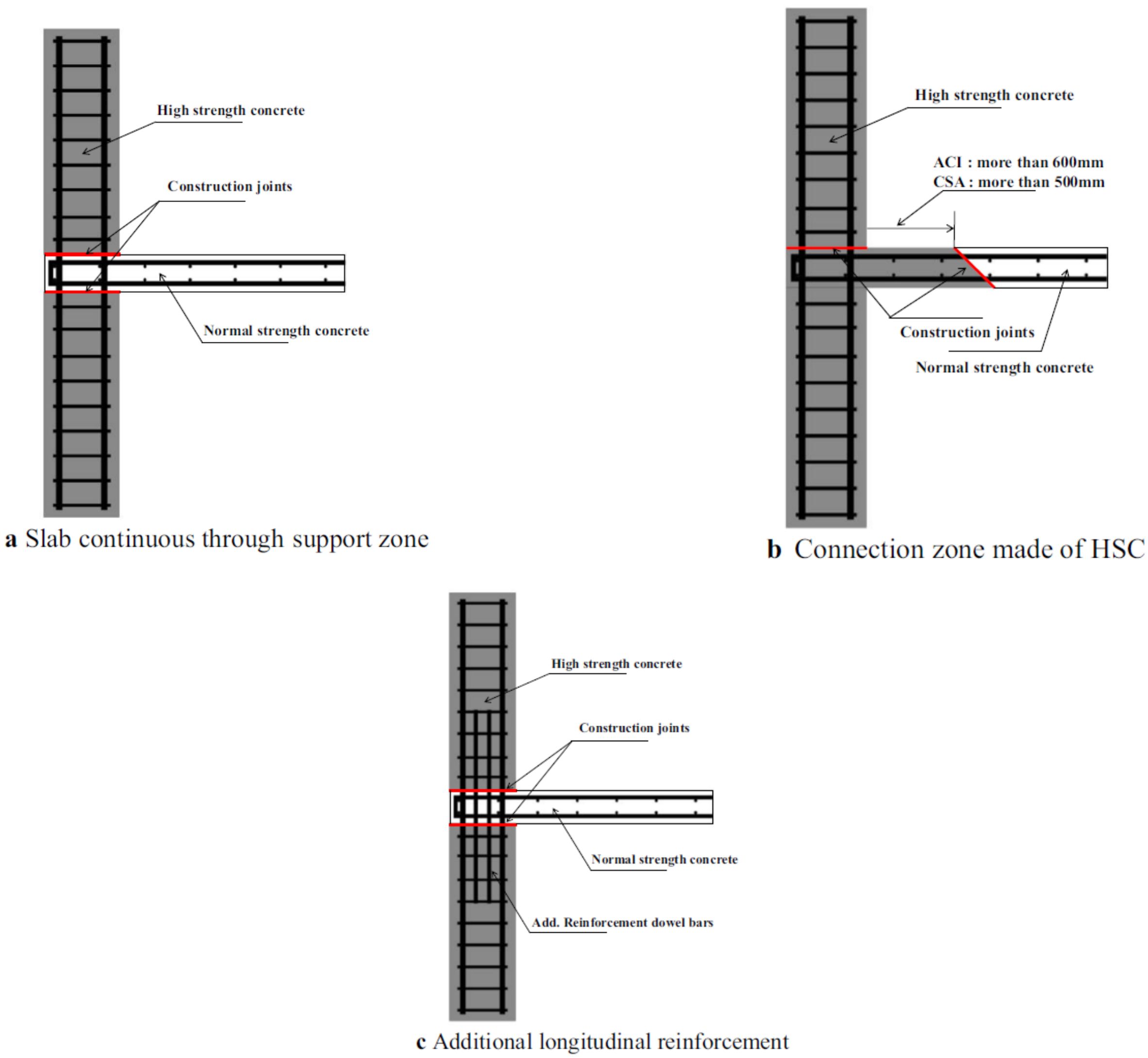

Figure 1 Type of column-slab connection

Many models of regression, empirical mainly, for the prediction of the effective strength of the column-slab junction, based on mechanics of structures and materials [4, to 10]. ACI code [1] propose that column strength ratios from column concrete to slab concrete strength up to

1.4 are not reduced for higher proportions. Experiments based by Bianchini et al. [5], to forecast the effective strength of the joint, the following statement was suggested:

f' ceff = 0.75f'cc + 0.35f'cs (1)

Where, f'cc and f'cs are respectively the column strength and slab concrete.

Gamble and Klinar [7] proposed the following for calculating the strength of a column-slab joint as a lower bound relationship:

f' ceff = 0.47f'cc + 0.67f'cs (2)

The ACI code [2] equation has been reported to be adequate for column concrete strength to slab concrete strength ratio of 1.4. But with the larger ratios, design provisions ACI code [2] overestimate and is therefore insecure the effective strength of the joints.

The Canadian Standard CSA-A23.3:1994[6] provides the following design expression in current design standards covering high strength concrete for greater column concrete strength to concrete strength slab:

f' ceff = 0.25f'cc + 1.05f'cs (3)

It seems safe to use, although extremely cautious, the effective strength prediction in CSA A23.3[6] design requirements.

The test programs of Bianchini et al. [5] are a noteworthy characteristic. Gamble and Klinar [7] was the absence of slab load. In reality, in a building prototype, the load on the slab produces substantial tensile stress in the top flexural slab reinforcement near the column. The assumption that this strain would have a harmful impact on the capacity of the surrounding slab to restrict the column-slab junction would be reasonable [8]. The new design models have been created by Ospina and Alexander [8] that incorporated the influence of the slab thickness-column ratio (aspect ratio, h/c). The design equation, proposed to estimate the effective joint strength, is as follows:

$$f'_{ceff} = \left(\frac{0.25}{h/c}\right) f'_{cc} + \left(1.4 - \frac{0.35}{h/c}\right) f'_{cs} \qquad (4)$$

In addition to the strength of the columns and slabs and the aspect ratio (h/c), impacts of the slab confinement and slab strengthening ratio surrounding, rs, predicting the effective strength of the joint should also be considered [9]. Based on the new parameters induction, the following equation predicting has been drawn up:

$$f'_{ceff} = 0.35\, f'_{cc} + 0.384\left(\frac{\rho s + 4.12}{h/c + 1.47}\right) \lambda f'_{cs} \qquad (5)$$

Recently, for the theoretical study of the problem, the mechanics of the material method, typically utilized for composite materials, have been adopted [10]. With the use of existing test data, this technique leads to a novel regression model for the effective strength calculation of the joint. Furthermore, the recent experiments [7, to 13] have tended to invalidate the limits ratio of 1.4 between the two concrete strengths, which ACI [1] allows in Sec. 10.15 of its construction code to be utilized without taking into account any unfavorable impacts on the column's axial load capability. The effective strength of the joint concrete has been determined to be commensurate with the product ratio and the total of the two concrete strengths as shown below:

$$f'_{ceff} = 2.25\left(\frac{f'cc * f'cs}{f'cc + f'cs}\right) \qquad (6)$$

This discovery leads to a comparison between the behavior of the column specimens and that of composites materials. The gathered test data shows that several mechanical principles of composite material are applicable to sandwiched concrete. In addition, it has been noted that several of the aforementioned models were built primarily for their own data by various scholars; Except the Shah et al. model [9] utilized by a wide range of data.

2. EXPERIMENTAL PROGRAM

2.1 Specimen Details

A total of three specimens were manufactured with a cross-section column (120x170) mm in length (800) mm. Cross-section beams in length (720) mm in the middle of the columns (100x200) mm). The heads of the columns on the top and the bottom (220x260) mm were given as shown Figure (2). The columns' compressive strengths were shown as the upper and lowers columns' average strengths, because they had the same mixing design. The concrete mix was designed, aiming at a compressive strength about 35MPa on the column and 25 MPa on the beam after 28 days. For the columns, the vertical longitudinal reinforcement of all specimen was 4 bars with diameter 10mm and the internal stirrups were 6mm diameter bars at 100mm from spacing. For all beams, both the top and the bottom of the longitudinal reinforcement were two bars of 10mm diameter and 6mm diameter bar internal stirrups of 100 mm spacing. The control specimen C0 in Figure (3) has no additional reinforcement, (C1-1&C1-2) contains extra internal stirrups in joint interaction between column-beam and their number (1&2) respectively with 6mm diameter bars. The specific parameter of each specimen is described in Table (1).

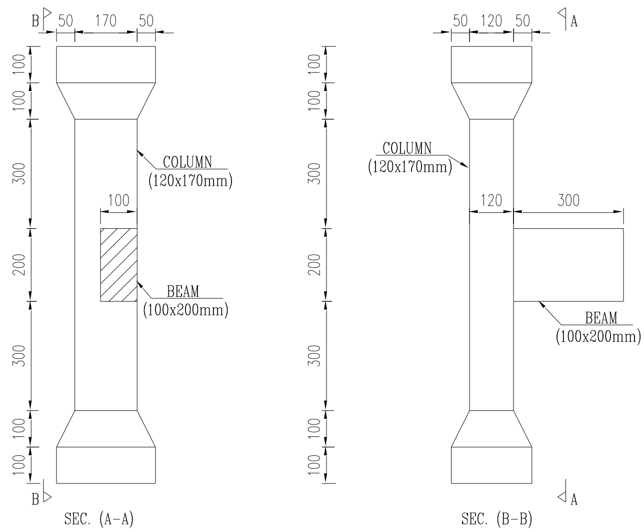

Figure 2 specimens' concrete dimension

Table 1 Specific parameter of each column

Column	Columns' compressive strengths (MPa)	Beams compressive strengths (MPa)	additional internal stirrups
C-0	35	25	-----
C 1-1	35	25	1 Ø 6
C 1-2	35	25	2 Ø 6

The test specimens consisted of three columns with different internal stirrups as shown in Figure (3).

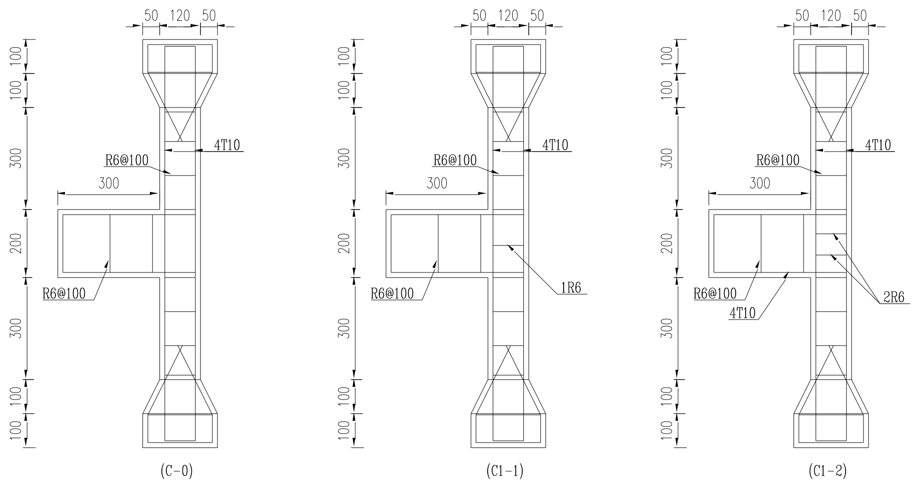

Figure 3 Details of reinforcement for all columns

2.2 Test Setup

The structural-testing machine in the Reinforced Concrete Laboratory at the Civil Engineering Department of Al-Azhar University was used to test. One hydraulic jack was used with capacity 100 Ton. Horizontal displacement at mid-point of columns was measured using LVDT, while strains of inner longitudinal reinforcement and strains of external stirrups were also observed. The vertical loads were measured at different stages of loading. The test setup is shown in Figure (4).

Figure 4: Test Setup

3. RESULTS AND DISCUSSION

The following observations have been concluded about the behavior of the columns tested:

3.1 Failure Loads

The failure loads of the tested columns were compared with estimated failure loads due to failure according to the American code (ACI -440) [1] and the Egyptian code (ECP-208) [2]. The failure mode in all specimens occurs in the beam column joint zone as shown in Figure (5). The experimental failure loads for all columns are shown in Figure (6) respectively.

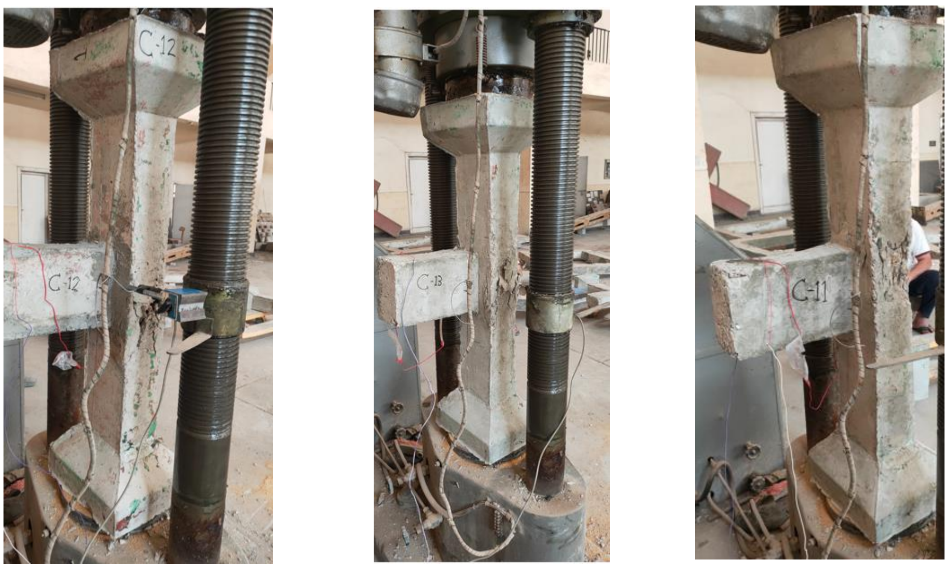

Figure 5 Cracks Pattern for All Columns

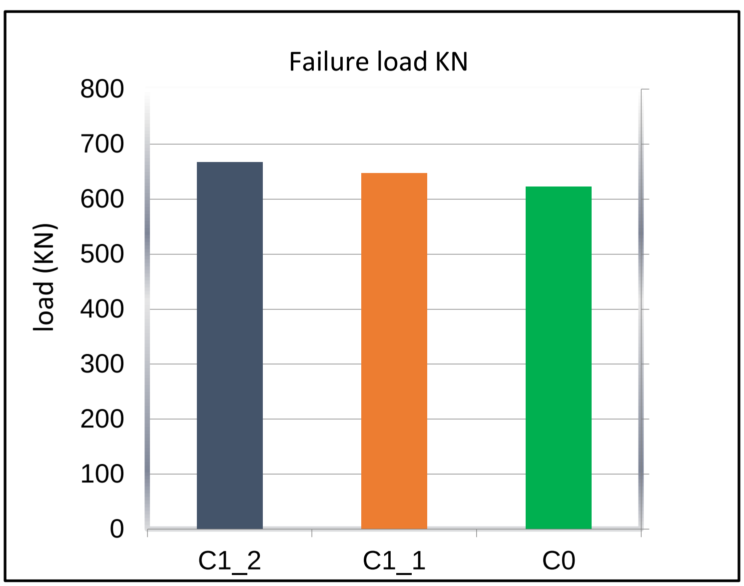

Figure 6: Failure Loads for All Columns

3.2 Steel Strains

The longitudinal steel strains were obtained from the electrical strain gauges. Figure (7) shows the load and longitudinal steel strain curves through the load history for all columns.

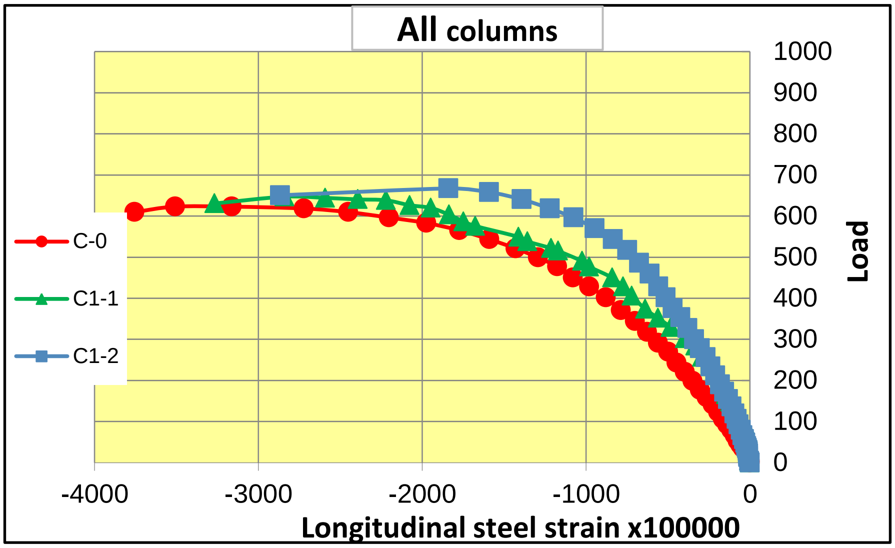

Figure 7: Load-Steel Strain Curves for All Columns

3.3 Discussion of Results

The experimental results showed the efficiency of the confinement of the specimen. The increase in column capacities ranged from 3.9% to 7.1%. This increase is due to the confinement of concrete by arching action between transverse steel (ties). Larger tie spacing (S) will result in less confined area and hence lower load-carrying capacity of concrete, whereas smaller tie spacing provides a better confinement, Mander et al (1988) as shown in Figure (8).

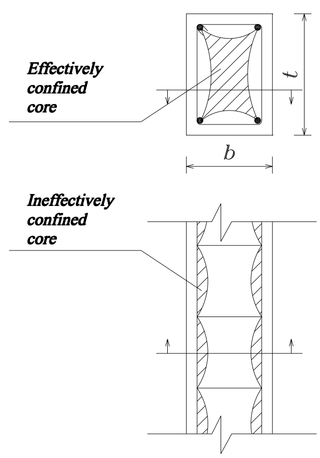

Figure 8 : Effectively confinement core for rectangular columns.

4. FINITE ELEMENT ANALYSIS

The specimens were modeled using finite element analysis. The used software was ABAQUS 6.12. The analysis was based on the non-linear iterative secant stiffness formulation. For compressive and tensile behavior, Concrete Damaged Plasticity model was used to describe the yield criterion of concrete. The stress strain curve of reinforcement was plotted as bilinear behavior. Cohesive Behavior model was used to describe the contact between concrete and outer stirrups (steel strips) with specified stiffness coefficients.

The deformed shapes of the Columns C 0, C 1-1 and C1-2 are shown in Figures 9,10and 11 respectively.

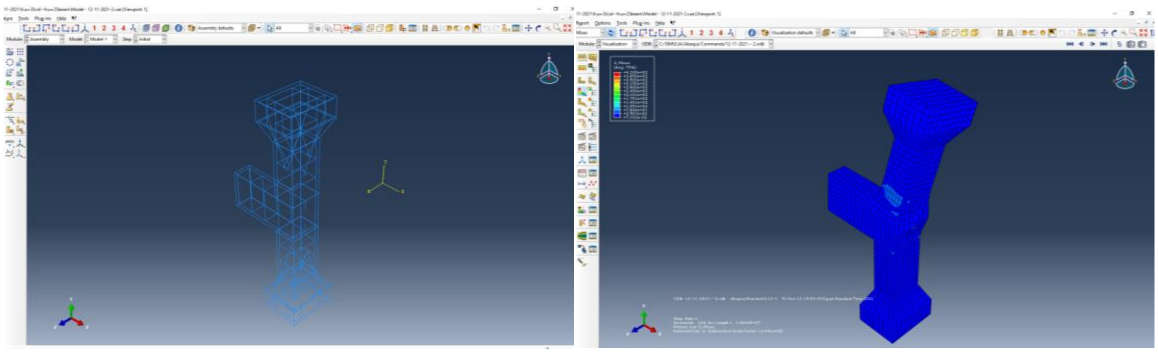

Figure 9: simulation of Column C 0

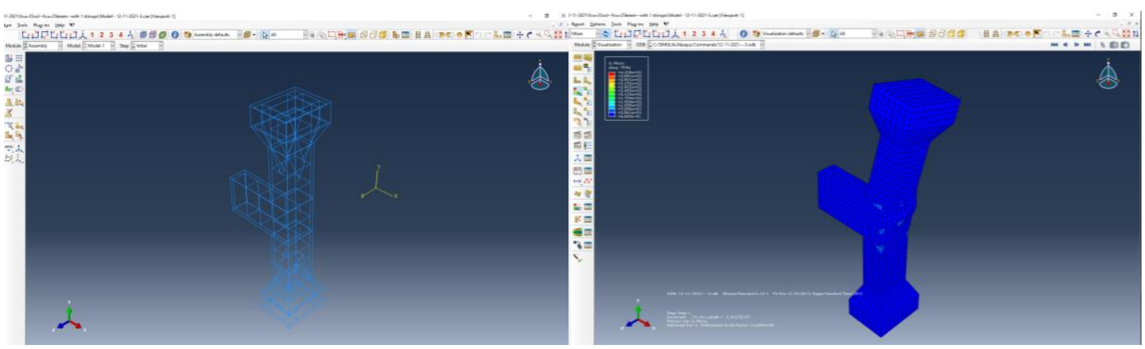

Figure 10: simulation of Column C 1-1

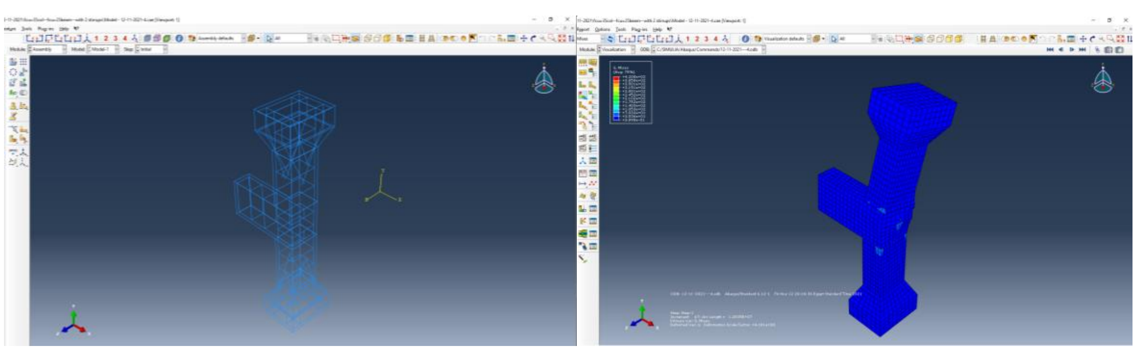

Figure 11: simulation of Column C 1-2

The experimental and theoretical failure loads are compared in Table 3. The failure was considered in the theoretical results when the stress in concrete began to decrease after that the strain in concrete began to reach 0.003. The difference between experimental and theoretical results was less than 8%.

Table 2: Comparison between Experimental and Theoretical Results

Column	Experimental Failure Loads (kN)	Theoretical Failure Loads (kN)
C-0	623	652
C 1-1	647	688
C 1-2	667	719

5. PARAMETRIC STUDY

The verification of numerical model has shown good agreement with experimental results. This justified a more global parametric study for strengthening of reinforced concrete columns at intersection with dropped beams. This parametric study would help in more knowledge of the behavior of other different columns, not tested in the laboratory.The first specimen in the parametric study is a column with dropped beam with the same concrete compressive strength to compare the behaviour of other columns. Table 3 shows the properties of each column in the parametric study and the failure load of each one.

Table 3 Specific parameter of each column

Column	Columns' compressive strengths (MPa)	Beams compressive strengths (MPa)	additional internal stirrups	Failur load
P-C-0	35	35	-----	814
P-C 1	35	25	4 Ø 6	742
P-C 2	35	25	6 Ø 6	789
P-C 3	35	25	9 Ø 6	801
P-C 4	35	25	11 Ø 6	815

The failure of all specimen occurred at the joint of dropped beams (zone with low concrete compressive strength) until the confinement result met the corossponding compressive strength of columns (high concrete compressive strength) then the failure occurred at the top of the columns as shown in Figure 12.

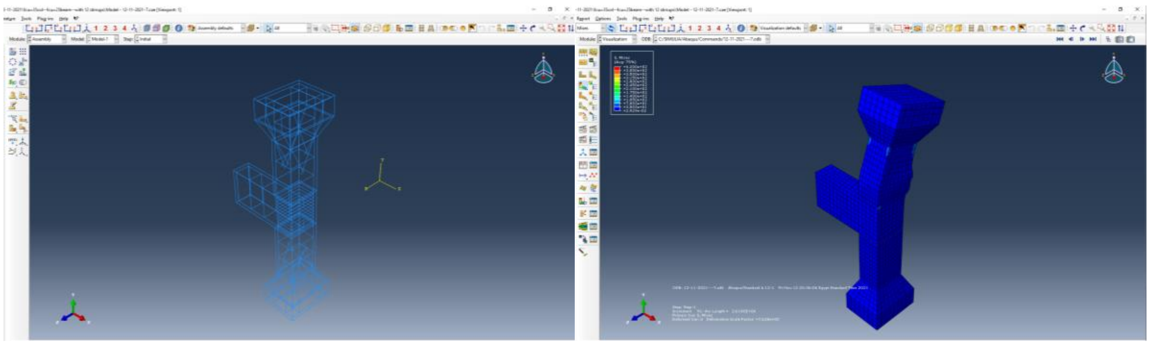

Figure 12: Simulation of Column P-C 4

6. CONCLUSIONS

The present study investigated the effect of the confinement of concrete columns at the weak joint with dropped beams. The following summarizes the findings of this investigation:

- A successful method for increase the capacity of beam column joint is by using additional steel stirrups which made a confinement zone of concrete which has lowest strength.
- Finite element models showed good agreement with the experimental results in the capacities. The difference between the experimental and theoretical results ranged between 4% to 8%.
- The ultimate failure loads of columns increased from 4% up to 30% with the increase in the confinement layers.
- Confinement of beam column joint can substitute the reduction of compressive strength at zone of intersection between columns and dropped beams.
- Based on the results of this study a full parametric study could be performed to pretend solid equations for the confinement of beam column joint with horizontal stirrups.

7. Reference

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