Behavior of Prestressing Bars in Reinforced Concrete Columns as Transverse Reinforcement

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Abstract:

This paper presents a practical confinement system for columns using skew prestressed bars as transverse reinforcement, applied on axially loaded square cross sectional reinforced concrete columns. The sustain confines the concrete members to sustain larger loads and to improve the total behavior of the member into a more ductile one. The effect of skew prestressed bars on reinforced concrete column was investigated in five square reinforced concrete columns specimens divided into two groups. The first group consists of three specimens with transverse reinforcement Y8 spaced at 100mm,150mm and 200mm.The second group consists of two specimens with transverse prestressed reinforcement T20 spaced at 100mm and 200mm. All specimens had the dimensions of 200mm*200mm with total height of 1850mm and they were tested under concentric compression. Crack loads, crack pattern, curves of load and axial deformations for each specimen were recorded. The study showed that the strength and ductility of concrete columns are generally improved due to confinement using skew transversed prestressed bars.

Keywords: Columns, Confinement, Transverse Prestressed Bars, Square Cross Section, Axial Load

1-INTRODUCTION

Reinforced concrete columns are the most critical members in any structure .Columns provide support for high compressive forces as vertical elements. Failure of one or more column may lead to collapse of the structure. For that there is a great demand for columns to be constructed using durable materials that could withstand aggressive environments. Increasing lateral confinement of reinforced concrete columns enhances the strength and ductility of the concrete columns in compression Mander et al [1]. The lateral confinement could be divided into two main types, either passive or active confinement, depending on whether lateral external confinement stresses were applied on the concrete member subjected to compressive load. The lateral pressure of passive confinement is caused by restraining the lateral strain expansion of concrete during compression loading. Fig.1 shows the profile stress diagram for both types of confinements.

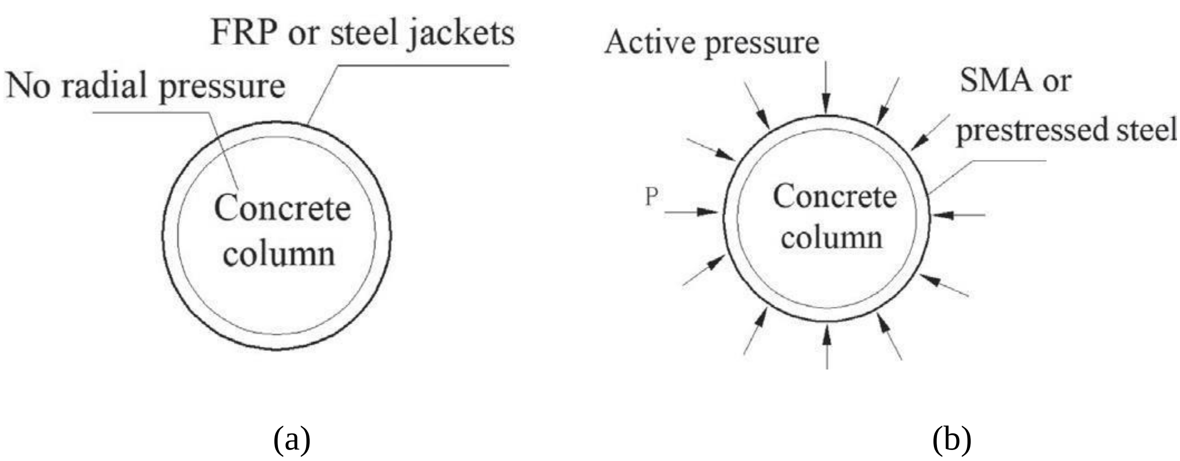


Fig.1 (a) passive and (b) active confinement on concrete column cross-sections [1].

To achieve a passive confinement for concrete columns transvers reinforcement is used. Most of the researchers studied the behavior of confined concrete with different types of transverse reinforcements. But there are a few researches on active confined concrete. In 2003, Staatcioglu and Yalan [2] revealed that both the strength and ductility of reinforced concrete columns is improved by using external prestressed steel strands that was used for strengthening, Hussain et al [3] studied the experimental tests on actively confined concrete using steel hollow section collars. Miyagi et al [4] conducted experimental tests on square reinforced concrete columns strengthened by using external prestressing bars and steel plates, Fakharifar [5] conducted a large-scale test on a damaged circular reinforced concrete column repaired with prestressing steel jackets. The prestressing steel jacket consisted of prestressed strands and thin steel sheet to protects the strands from damage due to the cracked concrete. The behavior of reinforced concrete columns using pretensioned FRP belts was studied by [6], Shin et al [7] showed that SMA [shape memory alloy] and prestressed steel strand confined concrete could provide lateral pressure at the initial stage of loading to solve the problem of stress lag. Applying active confinement through the prestressed steel strands needs more labor and mechanical equipment and the confined concrete may be destroyed, SMA or pre-stressed steel strands might penetrate the concrete, resulting in stress loss [8,2]

Increasing the ultimate compressive strength of concrete by approximately 25 percent when laterally confined with half the uniaxial ultimate compressive strength, but the percent of increase decreased from 25 to 16 % when increasing the confinement stress to the uniaxial ultimate compressive strength as shown in Fig .2 [9]

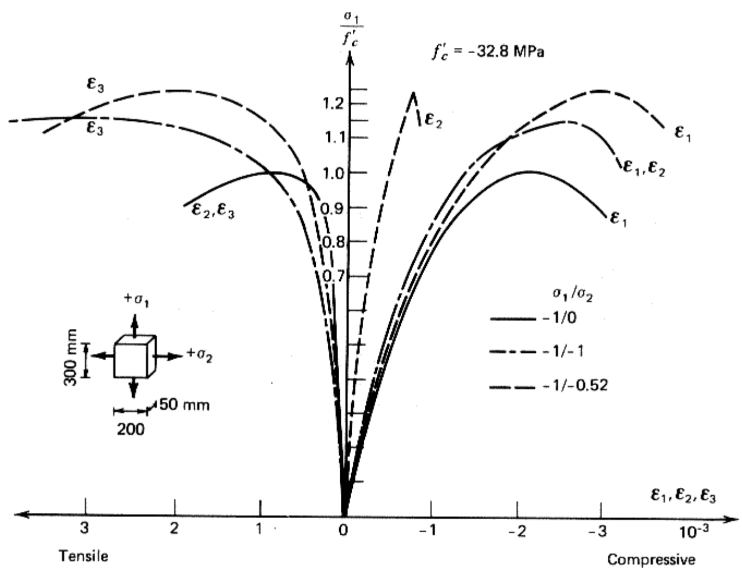


Fig.2 stress-strain relationships of concrete under biaxial compression test [9]

2-EXPERIMENTAL PROGRAM

This research uses prestressed bars as transvers reinforcement to improve the strength and ductility of reinforced concrete columns by introducing active confinement of the prestressed bars. To investigate the behavior of skew prestressing bars on reinforced concrete columns five reinforced concrete square cross section columns were tested under axial compression load. The five columns had a square cross-section of 200x200mm with height of 1500mm while the total column height was 1850mm as shown in Fig. 4. All tested columns were reinforced with the same longitudinal reinforcement 4 bars of diameter 12mm with a steel reinforcement ratio1.13%. The transvers reinforcement were divided into two group according to the type of confinement pattern. The first group consists of three reinforced concrete columns (RC10,RC15 and RC20) with transvers reinforcement 8mm diameter bar spaced 100mm,150mm and 200mm respectively to achieve the passive confinement, while the second group consisted of two reinforced concrete columns(CC10,CC20) with skew prestressing bars 20mm diameter high grade steel 10.9 as a transvers reinforcement spaced 100mm and 200mm respectively to achieve active confinement. The prestressing force (PS) was applied to the prestressing skew bars using a calibrated torque meter that produced 800 N.m on the prestressing bars to produce axial centric load of 200 KN on the bar.

Table (1): Details of the test specimens.

Group number	Column	Longitudinal Reinforcement	Transverse Reinforcement
I	RC10	4T12	Stirrups Y8@100mm
	RC15	4T12	Stirrups Y8@150mm
	RC20	4T12	Stirrups Y8@200mm
II	CC10	4T12	Prestressed bar T20@100mm
	CC20	4T12	Prestressed bar T20@200mm

2-1 Material properties

The concrete used had an average standard cube (150*150*150mm) compressive strength after 28 days (fcu) of 37.94 MPa. The equivalent standard cylinder (150x300mm) was tested to confirm compressive strength (f'c) of 34.18 MPa. The concrete mix used for casting all the columns was produced from ordinary Portland cement, natural sand and crushed dolomite with a maximum aggregate size of 20mm. The columns were demolded after 24 hrs, cured with water for 28 days.

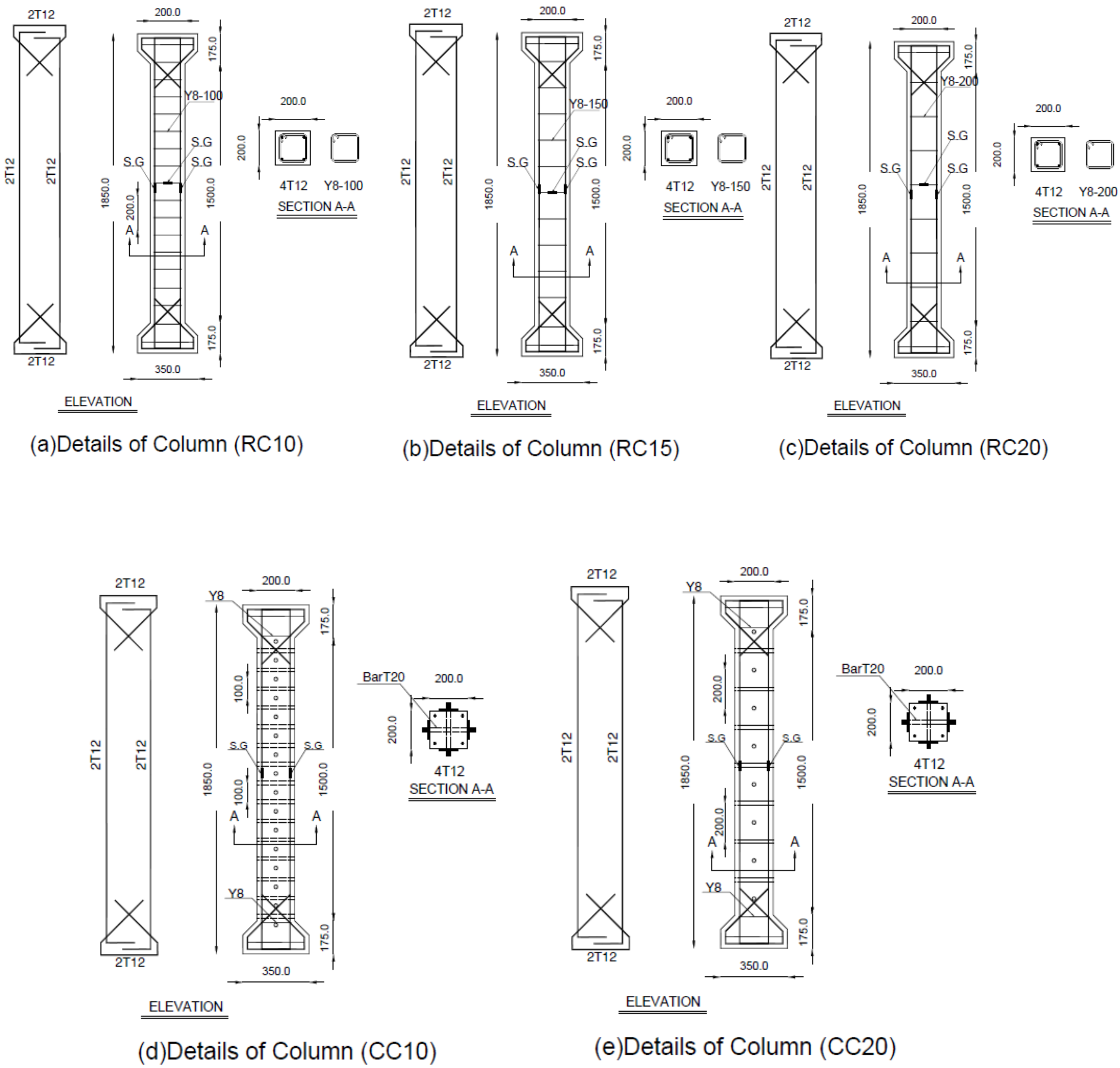
The mix proportions for one cubic meter of the used concrete is shown in Table (2)

Table (2): The concrete mix proportions used for columns specimens casting.

Mix Proportions (Kg/m3)				Slump (mm)
Cement	Dolomite	Sand	Water	
382	1196	563	210	60

Fig.3 Reinforcement arrangement of columns specimens in the steel formwork

Figure (3) shows the steel mould used formwork for casting the columns. The location of strain gauge points attached to the steel reinforcement is shown in Fig.4.



(a)Details of Column (RC10)
(b)Details of Column (RC15)
(c)Details of Column (RC20)
(d)Details of Column (CC10)
(e)Details of Column (CC20)

Fig.4 Details of Tested Columns

2-2 TEST SETUP

The columns were subjected to a monotonic uniaxial compression loading up to failure using a hydraulic jack machine, of capacity 150-ton. This machine was used for testing the five R.C columns. The load was measured using a digital load cell of 150-ton capacity. Linear variable distance transducer (LVDT) are used to measure both vertical and horizontal displacement of the specimens during testing. as shown in Figure (5). the specimens were loaded at a rate of 5-ton per minute using a load control system.

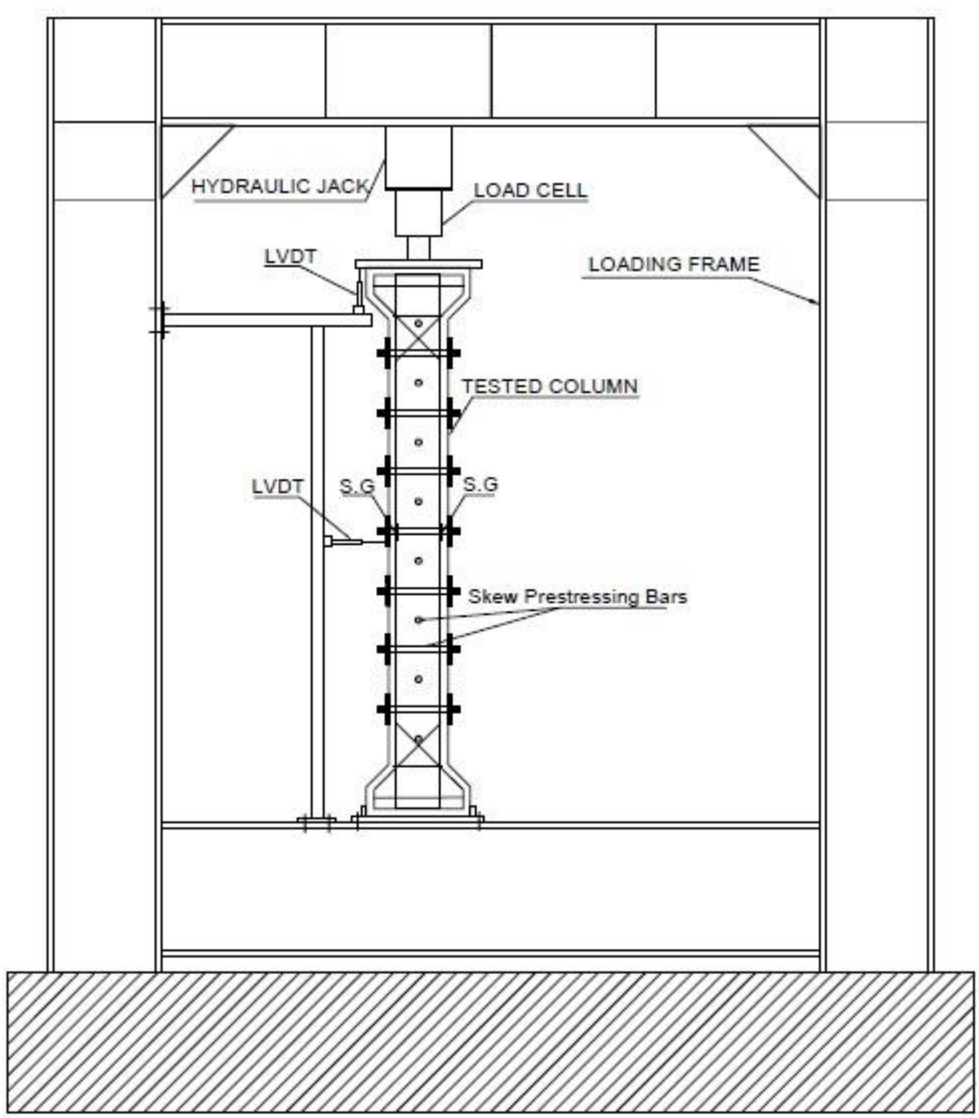


Fig.5 Schematic Diagram for Testing Frames and Test Setup

3- EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Mode of Failure

Figure (6) shows the crack pattern for the different tested specimens. The failure mechanisms of the columns with and without the skew prestressed bars were almost identical. First inclined cracks appeared at the edge of the upper third part or lower third part of the column which spread with the applied load. Under increased load the crack width increased and concrete cover spalled off. For column CC20, major inclined cracks spreaded from the upper third part to one of the column sides until failure at a load equal to 1220.778 KN. For the columns CC10, the same failure mechanisms appeared except that failure occurred at column lower third part at a load equal to 1286 KN. For the column RC20 inclined cracks spreaded from the upper third part to one of the column sides at a load equal to 738.558 KN. For the column RC15 inclined cracks spreaded from the upper and lower third part at a load equal to 777.64 KN. For the column RC10 inclined cracks spreaded from the upper and lower third part at a load equal to 852.51 KN. Figure (6) shows the cracks patterns for tested columns.

Fig.6 (a). Crack Patterns for Specimen CC20

Fig.6 (b). Crack Patterns for Specimen CC10

RC20

RC15

RC10

Fig.6 (c). Crack Patterns for Specimen (RC20, RC15and RC10)

Table (3): The Experimental Results of the Tested Columns.

Group number	Column	Axial Displacement (mm)	Ultimate load (KN)	Energy Absorption (KN.mm)
I	RC10	7.5	852.5	3986.8
	RC15	6.7	777.6	3179.1
	RC20	5.9	738.5	2419.7
II	CC10	10.2	1286	8033.4
	CC20	9.7	1220.8	6718.1

3.2. Load-axial displacement behavior

The axial displacement of all specimens had been measured at each increment of loading. The measured displacement of columns were plotted against the load. All curves indicated that the relation between load and axial displacement was nearly linear up to cracking load, then excessive cracking in concrete leads to excessive deformations and nonlinear distributions.

3.2.1 Effect of Passive Confinement on the Behavior of R.C Columns

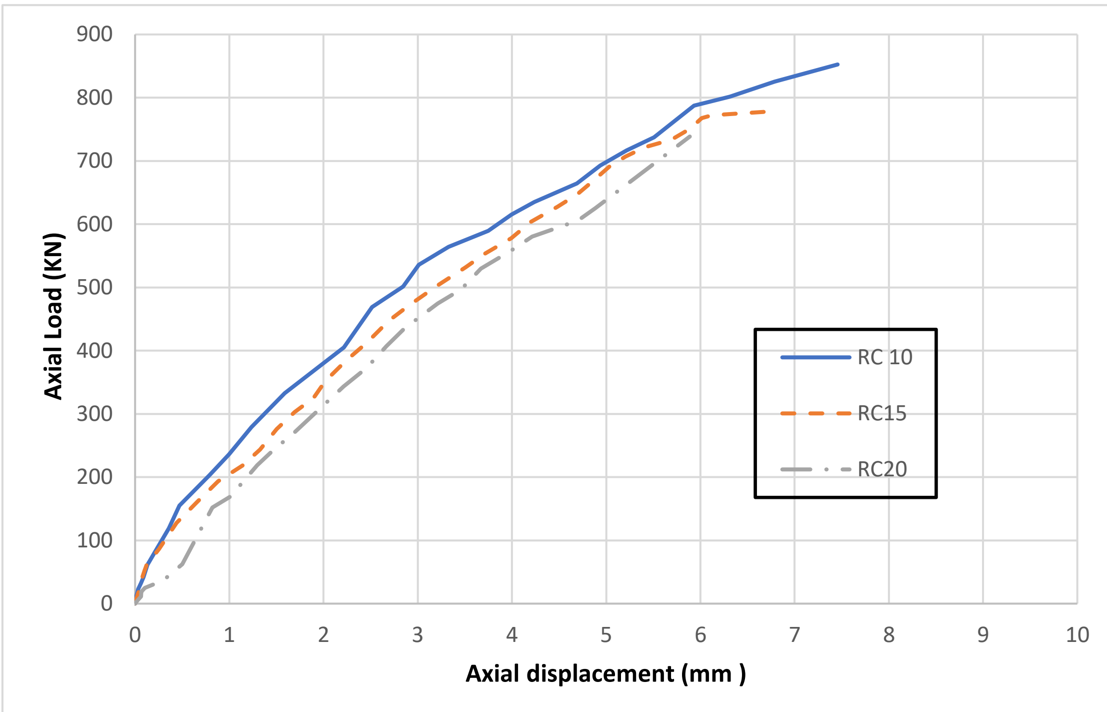


Fig.7 Effect of Passive Confinement

From Figure (7) it is clear that decreasing the stirrups spacing increase the passive pressure applied to the column. Since the ultimate axial load of RC10 with stirrups spaced 100 mm increased by 10% and 15.43% than that of RC15 with stirrups spaced 150 mm and RC20 with stirrups spaced 200mm respectively. The max axial displacement of RC10 increased by 11.62% and 26.66% than that of RC15 and RC20 respectively. The effect of transverse reinforcement ratio on failure load shown in Figure (8).

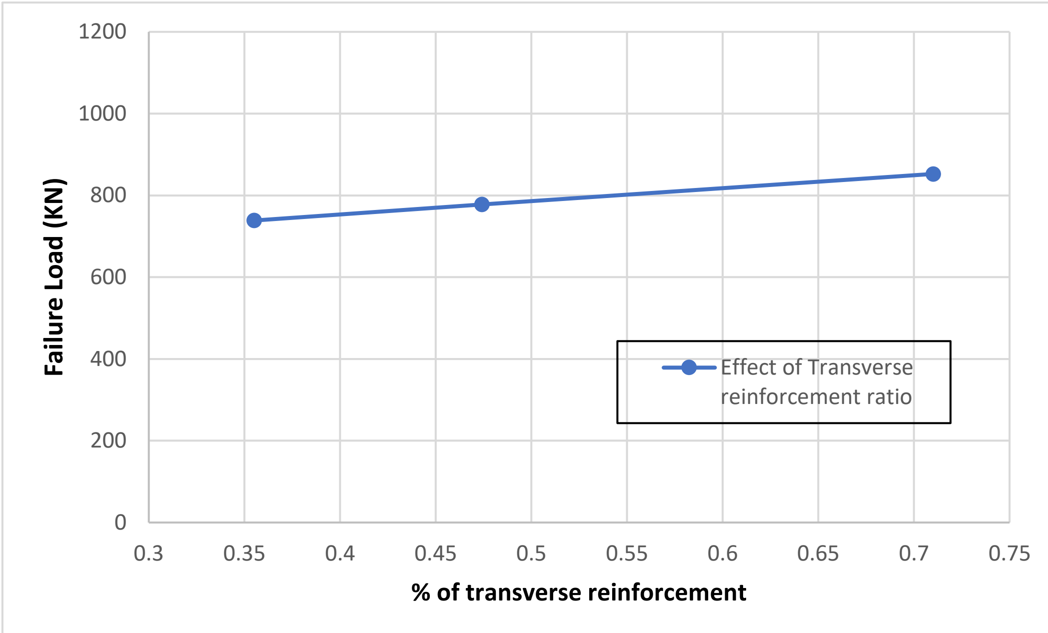


Fig.8 Effect of Transverse Reinforcement Ratio on Failure load

3.2.2 Effect of Active Confinement on the Behavior of R.C Columns

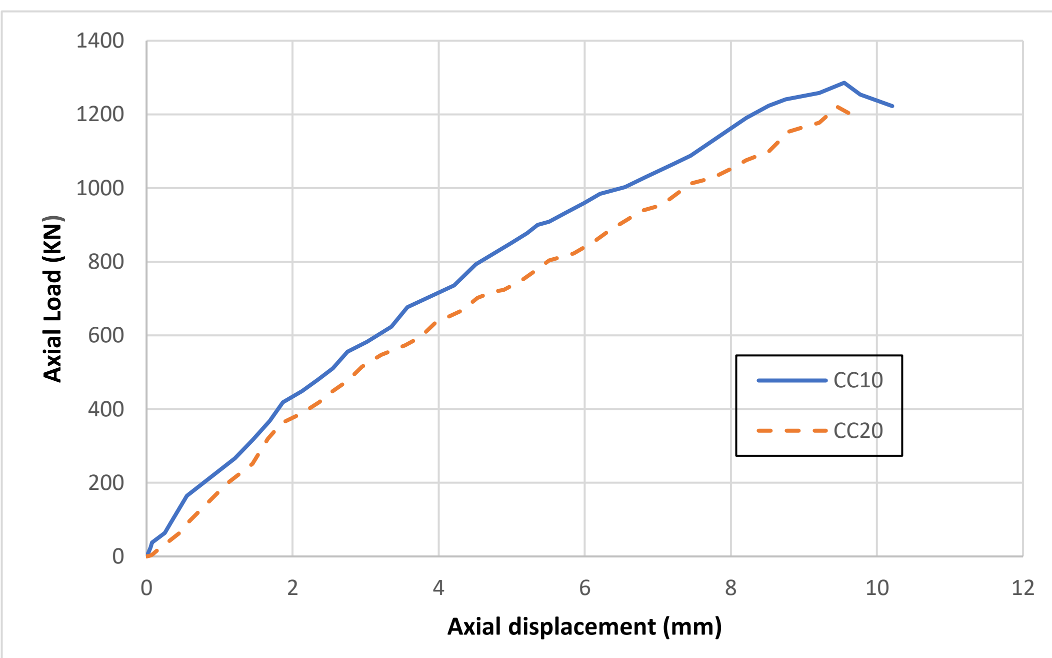


Fig.9 Effect of Active Confinement

From Figure (9) it was clear that decreasing the spacing between the skew prestressing bars from 200 to 100 mm did not have a significant effect on the failure load. Since the ultimate axial load of CC10 with skew prestressing bars spaced 100 mm increased by 5.41% than that of CC20 with skew prestressing bars spaced 200mm. The max axial displacement of CC10 increased by 4.83% than that of CC20. The effect of transverse stress on failure load shown in Figure (10).

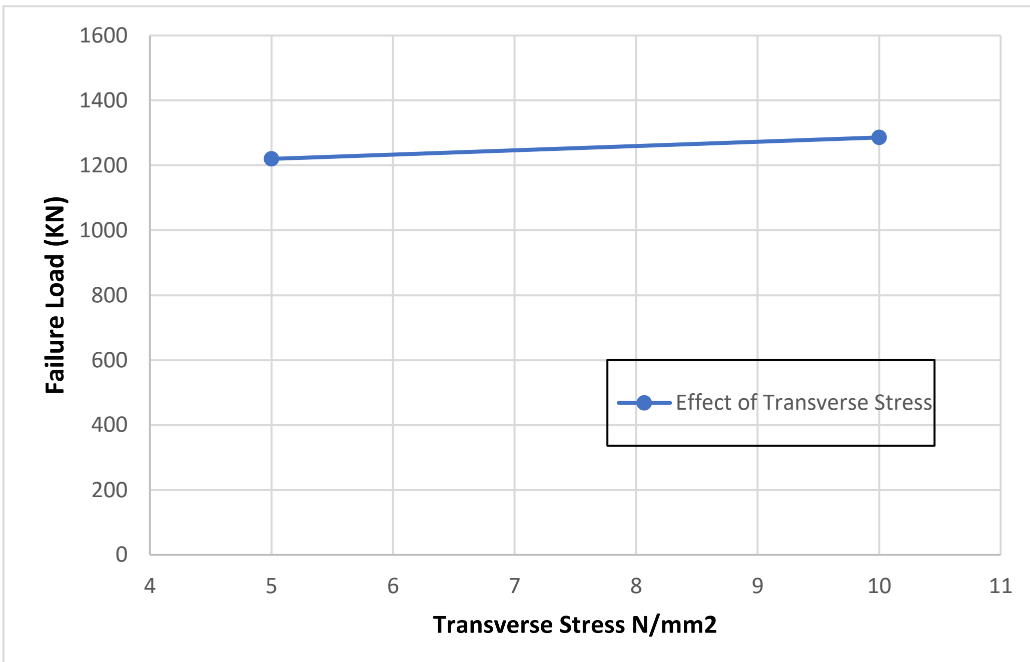


Fig.10 Effect of Transverse Stress on Failure load

3.2.3 Effect of Transvers Reinforcement Type on the Behavior of R.C Columns

From Figure 11(a) shows the effect of transverse reinforcement of spacing 100 mm on the column behavior. The active pressure used in column CC10 increased the ultimate axial load of column by 50.85% than that of passive confinement of RC10 using the same spacing between transverse reinforcement. The max axial displacement of column CC10 increased by 36.94% than that of RC10.

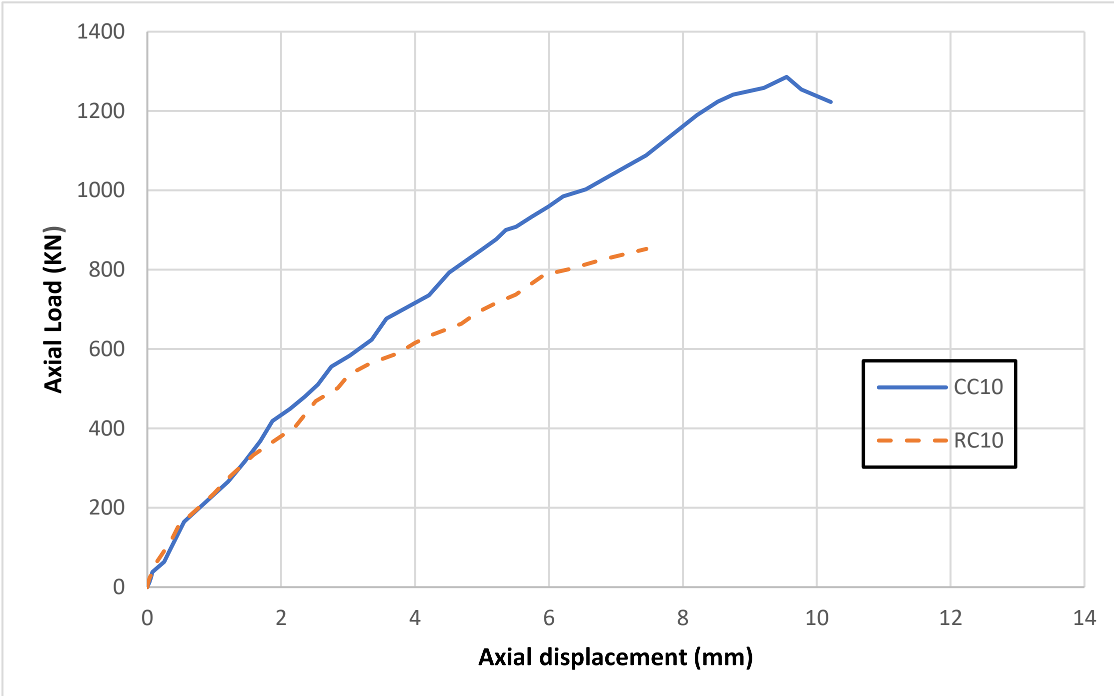


Fig.11(a) Load – Axial displacement relationship of CC10 and RC10

From Figure 11(b) shows the effect of transverse reinforcement of spacing 200mm on the column behavior. The active pressure used in column CC20 increased the ultimate axial load of column by 65.29% than that of passive confinement of RC20 using the same spacing between transverse reinforcement. The max axial displacement of column CC20 increased by 65.45% than that of RC20.

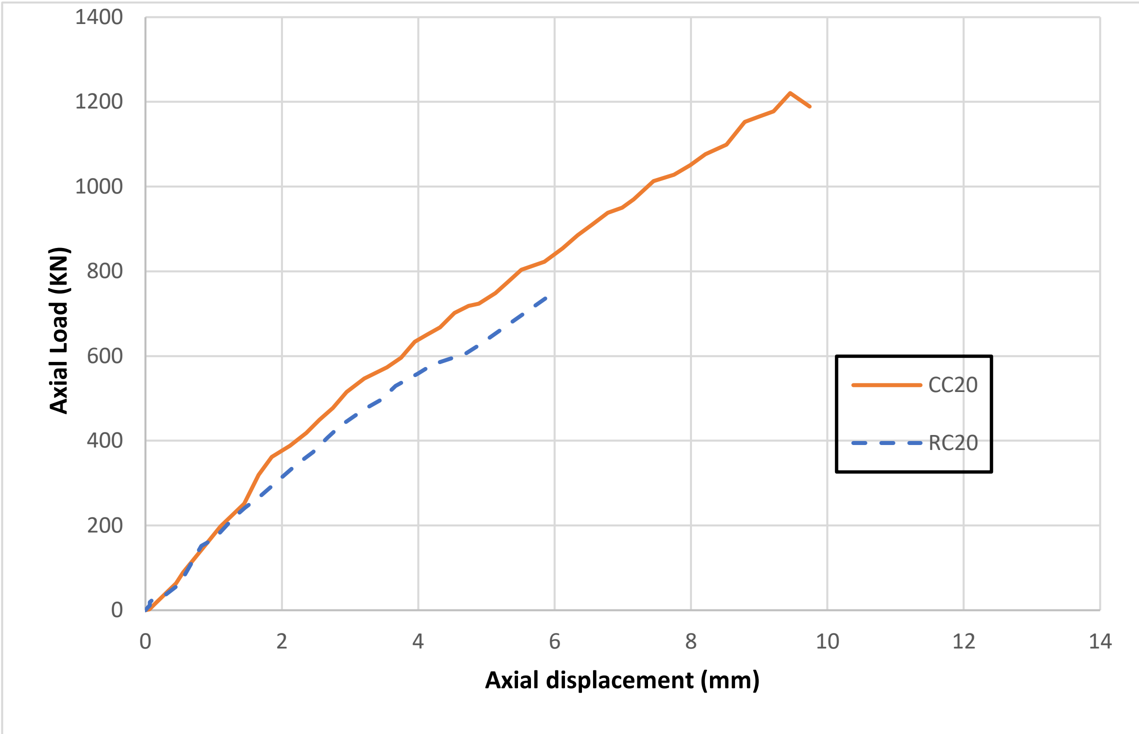


Fig.11(b) Load – Axial displacement relationship of CC20 and RC20

3.3. Energy absorption

The energy was estimated by calculating the area under load – axial displacement curve for each specimen. The area provided an indication to the total energy absorbed by the structure or element under the applied load and can provide information about the R.C columns ductility. From Figure (12) it is clear that the total absorbed energy by active confinement of skew prestressing bars (CC10, CC20) were higher than that of the total absorbed energy of passive confinement by stirrups of the column. It is clear that decreasing the stirrups spacing increase the passive pressure applied to the column. Since the total absorbed energy of RC10 increased by 25.41% and 64.77% than that of RC15 and RC20 respectively. Also decreasing the skew prestressing bars spacing increase active pressure applied to the column. Since the total absorbed energy of CC10 increased by 19.58% than that of CC20. The total absorbed energy of the active pressure used in column CC10 and CC20 increased by 101.52% and 177.64% than that of RC10 and RC20 respectively using the same spacing between stirrups that provided passive pressure as a transvers reinforcement. It was clear even for minimum active pressure provided by skew prestressing bars spaced 200mm CC20 the total absorbed energy was increased by 68.50% than that for maximum provided passive pressure RC10 with maximum spacing 100mm between the transverse reinforcement.

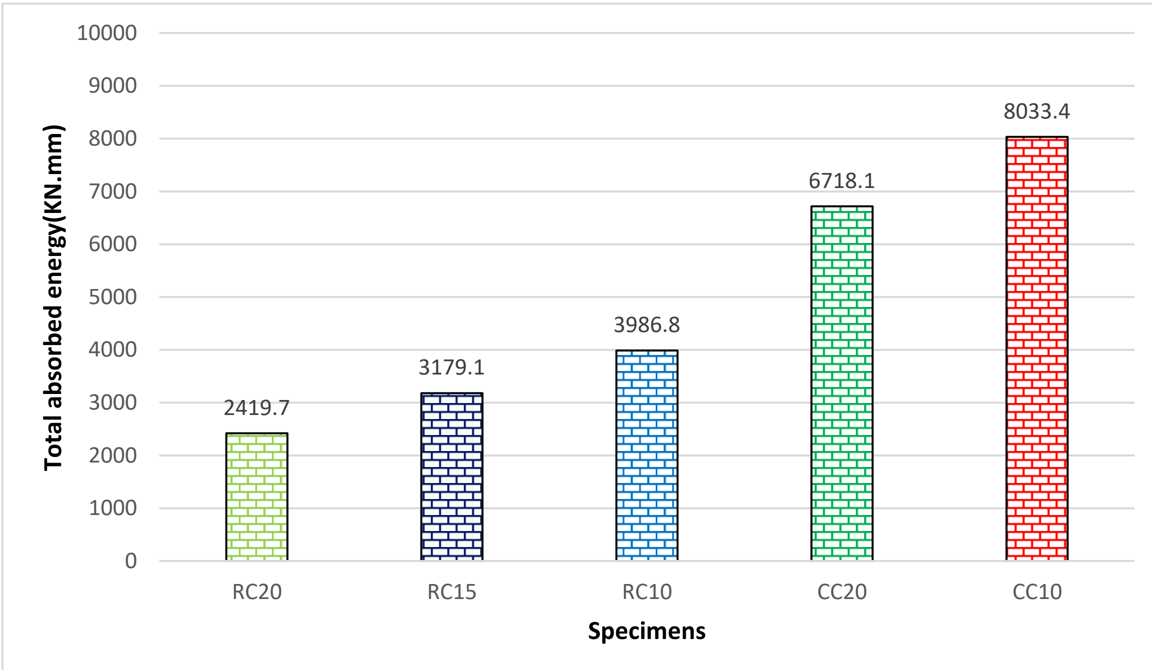


Fig.12 Total absorbed energy of specimens

4- CONCLUSIONS

Based on the previous results and discussion, the following could be concluded:
1- increasing the distance between the transvers reinforcement reduced the passive pressure leading to the decrease of the vertical load capacity for all specimens of transverse reinforcement.
2- increasing the distance between the skew prestressing bars provided small active pressure that reduce the vertical load capacity for all specimens of skew prestressing bars.
3- The active pressure used in column CC10 increased the ultimate axial load of column by 50.85% than that of passive confinement of RC10 using the same spacing between transverse reinforcement and increased the max axial displacement of column CC10 by 36.94% than that of RC10.

4- The active pressure used in column CC20 increased the ultimate axial load of column by 65.29% than that of passive confinement of RC20 using the same spacing between transverse reinforcement and increased the max axial displacement of column CC20 by 65.45% than that of RC20.
5- Confinement of square reinforced concrete columns with skew prestressing bars generally leads to improvement of the ductility of the columns and axial load carrying capacity
6- The percentage of the increase in the ultimate axial load and axial displacement with confinement by stirrups was generally small compared to the confinement by skew prestressed bars.
7- The ultimate axial load and ductility is directly proportional to the lateral confinement of the prestressing bar and inversely proportional to the spacing between prestressing skew bars.

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