LATERAL CONFINEMENT OF RC SHORT COLUMN

Shafqat A & Ali A.
Civil Engg. Department, University of .Engineering & Technology. Lahore. Pakistan

ABSTRACT: *Columns are important structural member subjected to mainly axial forces with or without the moment whose failure leads to collapse of a structure. Under the application of load, column shortens longitudinally and expands laterally. This lateral expansion is pronounced when the stresses exceed 70% of column strength. On application of maximum axial load, the concrete crushes and the longitudinal reinforcement buckles outwards.*

Experimental investigations have been made by changing the conventional lateral ties of rectangular RC column core to special confinement using the equivalent area of thin steel plates. Three columns were casted using different confining steel. Experimentation was done on these columns to check the maximum axial capacity along with study of mode of failure and toughness.

Experimental work on a tied column showed that strain in confining reinforcement was only 20% of main reinforcing steel strain at first peak and stress level in confining steel was only 28.45% of its yield stress for controlled column using normal ties. It is clear from above results that at the time of maximum load, stresses in confining steel are significantly lesser than its capacity. So this reserve capacity can be utilized by spreading the area of lateral reinforcement over the longitudinal steel bar in order to reduce the effective length.

Keywords: Lateral confinement of columns, Steel plates in place of rebar ties in columns, Lateral strains in column, Reinforcement

INTRODUCTION:

Over 90% of columns in buildings in non-seismic areas are tied columns. In such columns, the ties are spaced according to the ACI criterion (roughly least lateral dimension of a column) and as a result, relatively slight lateral restrain to the column core is produced. Outward pressure on the sides of the ties due to lateral expansion of the core buckles the longitudinal steel outward. A great deal of work showed that ACI code minimum lateral confinement has little or no role during the ascending of the loading and concrete cover is visually free of cracks up to the first peak when the column is subjected to axial loading.

Concrete cover suddenly shows cracks at above mentioned load level, the stress in the transverse reinforcement is generally less than the 50% of the ties yield stress. As a result, the concrete of column core loses its axial strength by 10- 15 % of its maximum value due to sudden spalling of the concrete cover. At this stage, lateral concrete strain increases considerably and as a result, the passive confinement becomes extremely significant for the concrete core to sustain load.

This work was aimed to increase the passive confinement (as in the case of spirally reinforced circular column) of axially loaded rectangular tied columns replacing the traditional lateral reinforcement to equivalent steel plate strips. Ties reduce the unsupported length of the longitudinal bars, thus reducing the danger of buckling of those bars as the bar stress approaches to yield. [1]

Objectives of this research work were:

i. To study the effect of lateral confinement on column core which is likely to enhance axial capacity of the column.
ii. To determine the role of core confinement towards post-peak behavior of rectangular reinforce concrete column.

   In order to study the effect of lateral confinement on compressive strength of axially loaded rectangular tied column, the variables are concrete compressive strength, ties yield strength and configuration, the volumetric ratio of the transverse reinforcement, the tie spacing, and the volumetric ratio of the longitudinal reinforcement. However, this was replaced by emphasizing a change in traditional steel ties to equivalent thin steel strips, thinking that confinement provided by the equivalent area steel will be more effective as compared to circular ties.

On the basis of lateral confinement type and arrangement, columns may be classified as:

i. Columns reinforced with longitudinal bars and confined with lateral ties.
ii. Circular columns reinforced with longitudinal bars and laterally confined with spiral reinforcement.
iii. Composite columns in which steel structural shapes are encased in concrete.

According to function, there are two types of reinforcement of column.

a. Longitudinal Reinforcement:

To take care of the moments and axial forces in columns reinforcing bars are provided parallel to the longitudinal axis of columns.

b. Lateral Reinforcement:

It is provided to restrain local buckling, provide shear resistance, hold longitudinal steel and confines concrete.

It is of three types; lateral bar and equivalent plate ties and spiral ties.

1.1 Effect of Variables on Behaviour of Confined Concrete:

a. Compression strength of concrete

Due to higher modules of elasticity and lower internal cracking high strength concrete exhibits less lateral expansion under axial compressive loads as compared to normal strength concrete. Further, relatively more efficiency may be observed in terms of greater strength and toughness for lower strength concrete, [2]

b. Volumetric ratio of transverse reinforcement (ρt):

The confining pressure applied on the core of concrete column is directly related to the volumetric ratio (ρt) of transverse reinforcement. With increase in lateral confining pressure applied on the concrete core better will be the confining efficiency. It follows that volumetric ratio of transverse steel is proportionally related to peak strength and toughness of concrete as shown in arching effect, Fig 2.

c. Yield strength of confining steel (fyt):

Yield strength of transverse steel measures the upper limit of the confining pressure applied to the concrete of column core. A higher confining pressure applied to the concrete core can result as more confinement efficiency.

d. Configuration of transverse reinforcement:

The configuration of transverse reinforcement reflects the effectively confined concrete area. Properly configured column would result in effectively confined concrete core of higher confinement efficiency.

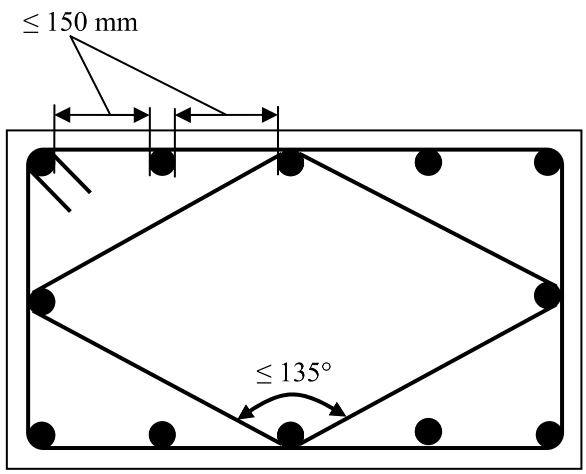

Fig 1: Tie Configuration (ACI 2005)

e. Spacing of transverse reinforcement (s):

A smaller tie spacing results in better confined concrete area and reflects the high confinement efficiency.

f. Volumetric ratio of longitudinal steel (ρe):

High volumetric ratio of longitudinal reinforcement provided by the larger steel bar diameter would avoid the buckling of longitudinal bars.

2. Confinement Action of Lateral Reinforcement

It is necessary to understand the phenomenon or mechanism of lateral reinforcement by which it confines the column concrete core. Based on experimental data and analytical investigation of column tests, a number of workers concluded that area of efficiently confined concrete is lesser as compared to area bounded by the tie circumference. It can be said that Ach > Ae, Fig 1 & 3. [2,3]

2.1 Axial Load and Deformability of Column

The effect of axial load on deformability of concrete column has been studied by many researchers. Their conclusion is that the effect of axial compression is to reduce column deformability. [4]

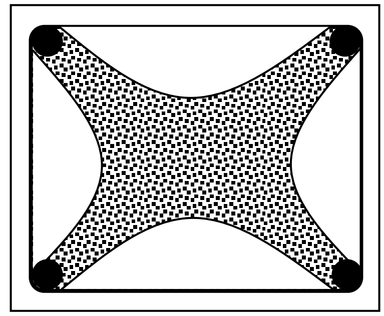

Fig 2: Arching Effect

If A_{ch} is the area of concrete increased by the perimeter of tie and A_e is the effectively confined concrete area.

The lateral confinement pressure (f'_e) will be

$$f'_e = f_e K_e \qquad (1)$$

Where K_e is confinement effectiveness coefficient, it can be expressed as

$$K_e = Ae/Acc \qquad (2)$$

Where

A_{cc}= Area of core within center line of the perimeter ties without longitudinal steel area, can be written as:

$$A_{cc} = A_c\,(1 + \rho_l) \qquad (3)$$

Where

P_l = longitudinal reinforcement ratio.

A_e = Effectively confined concrete area.

For various configuration of confinement, lateral confinement pressure f_e can be determined using Fig 3.

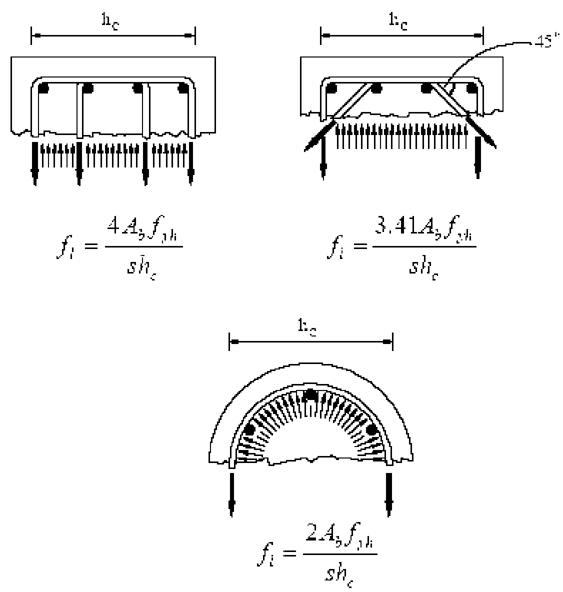

Fig 3: Confining Pressure Provided by Different Configuration of Transverse Steel, [5]

Normally, interaction curve has been drawn between axial load and moment capacity which is generally used for column design. Similarly, axial load verses curvature diagram can be drawn Using these curves ductility can be assessed at different axial load levels.

.

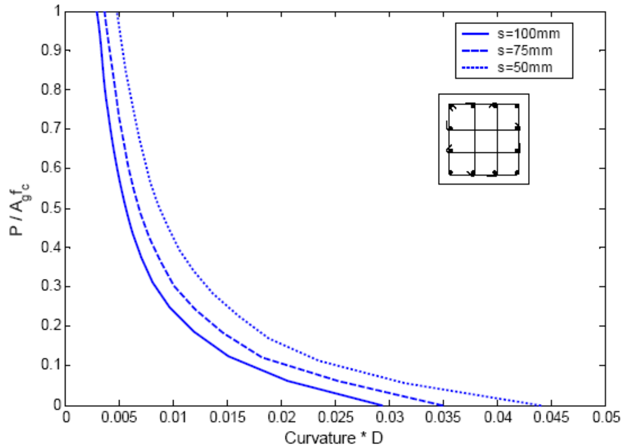

Fig 4: Axial load ~ Curvature Curve [6]

3. Experimental investigation:

3.1 Specimen Properties:

In this research, three columns were selected each having the same size of 150 mm square with the following ties configuration having the same cross sectional area.

CSB1 = Concrete column confined with conventional steel ties referred to as control column.

CSP1 = Concrete column confined with 2mm thick steel strips.

CSP2 =Concrete column confined with 1.2mm thick steel strips.

a. Cross sectional dimensions:

All the specimens were prepared without concrete cover due to reasons mentioned below:

- According to ACI Code capacity of columns should be same before and after spalling of concrete cover.
- Concrete cover was neglected as it has no structural considerations and provided only for protection against corrosion and fire to the steel reinforcement.
- Suddenly spalling of concrete cover can reduce load carrying capacity.
- Due to provision of steel strips, it can cause the difficulty during pouring of concrete.
- Purpose of this research was to study the concrete core (buckling of longitudinal bars and failure of confining steel) at time of failure. Concrete cover may effect the objectives.

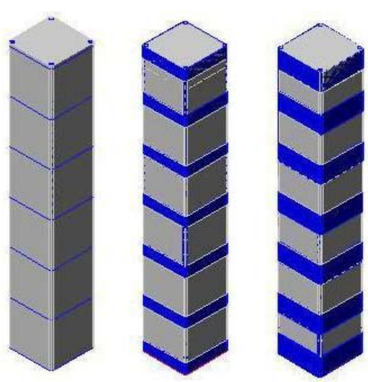

Fig 5: 3D Specimen Columns View

b. Height of specimen:

For all the specimens 910 mm height was selected. As a result, specimens fall in the category of short column.

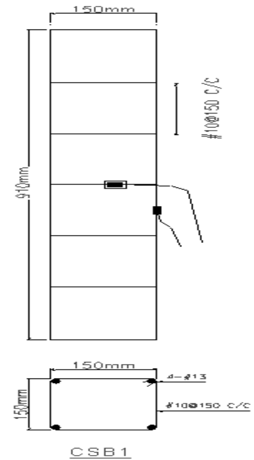

Fig 6a: Overall dimension and reinforcement details of test specimen CSB1

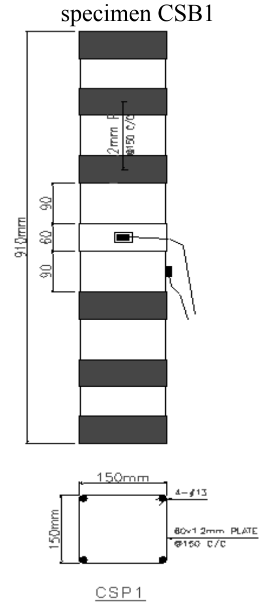

Fig 6b: Overall dimension and reinforcement details of test specimen CSP1

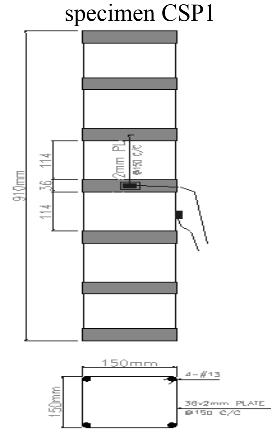

Fig 6c: Overall dimension and reinforcement details of test specimen CSP2

c. Reinforcement details of specimens:

a) CSB1

The reinforcement details of controlled column designated as CSB1 were as under:

- Four No. 13 diameter bas for longitudinal steel and has a reinforcement ration of 2.3% which satisfied ACI (10.9.1)
- Magnitude and spacing of transverse reinforcement was maintained according to ACI (7.10.5.1, 2 and 3)
  - 48 times of transverse steel diameter.
  - 16 times of longitudinal steel diameter.
  - Least column dimension.
  - Least of the above three was 150 mm, so No. 10 @ 150 mm c/c ties were provided.

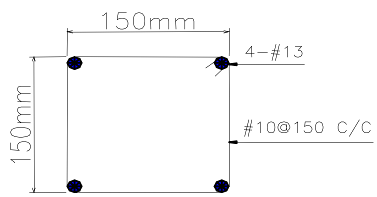

Fig 7: CSB1

Note that all the lateral ties were provided by 135^0 hooks around one longitudinal bar and extension of hooks were 50 mm into the concrete core.

b) CSP1

- Specimen CSP2 has same longitudinal steel as control column (CSB1).
- Amount and spacing of transverse reinforcement were also same as for (CSB1) but the difference was the shape of confinement. In this column steel bar was replaced with equivalent area steel strip 2mm thick and 36 mm wide.

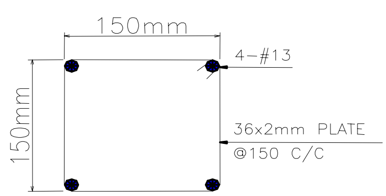

Fig 8: CSP1

c) CSP2

- The specimen was confined by 1.2 mm x 60 mm steel strip at 150 mm centre to centre spacing.
- Remaining details were same as CSP1

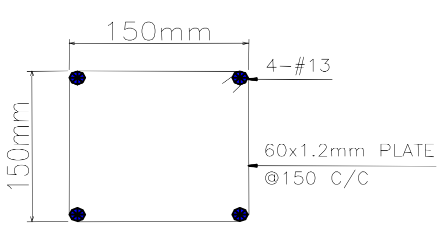

Fig 9: CSP2

3.2 Material Properties:

a. Concrete:

Compressive strength of concrete was considered as constant for all the specimens. A concrete mix was designed with specified 28 days cylinder strength of 18 MPa.

b. Steel:

Table 1:Steel Properties:

Designation	Material Description	Strength (MPa)
CSB1	Concrete fc'	18.93
	Main steel f_{yv}	465.4
	f_{tv}	689.5
	Tran. steel f_{yt}	305.2
	f_{tt}	456.2
CSP1	Concrete fc'	18.7
	Main steel f_{yv}	465.4
	f_{tv}	689.5
	Tran. steel f_{yt}	310.0
	f_{tt}	477.9
CSP2	Concrete fc'	17.83
	Main steel f_{yv}	465.4
	f_{tv}	689.5
	Tran. steel f_{yt}	311.0
	f_{tt}	463.3

3.3 Instrumentation and Measurements

An axial compressive load was applied using SHIMADZU Universal Testing Machine with maximum capacity of 200 Tons. Overall view of experimental setup with loading devices and measuring system is shown in Fig 10. A strain gauge was fixed to record lateral strain. Further, LVDTs were installed to measure vertical and horizontal displacements for each of the three columns investigated. [7]

3.4 RESULTS

Controlled column (CSB1)

The strain applied on controlled column with equal increment of axial loading to the results given below in Table 2. Its failure is shown in Fig 14.

3.5 Controlled column (CSB1)

The strain applied on controlled column with equal increment of axial loading to the results given below in Table 2. Its failure is shown in Fig 14.

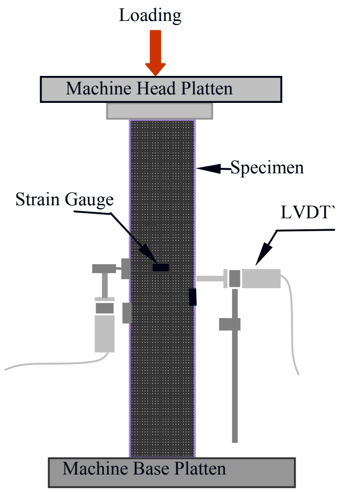

Fig 10: Schematic diagram for experimental setup

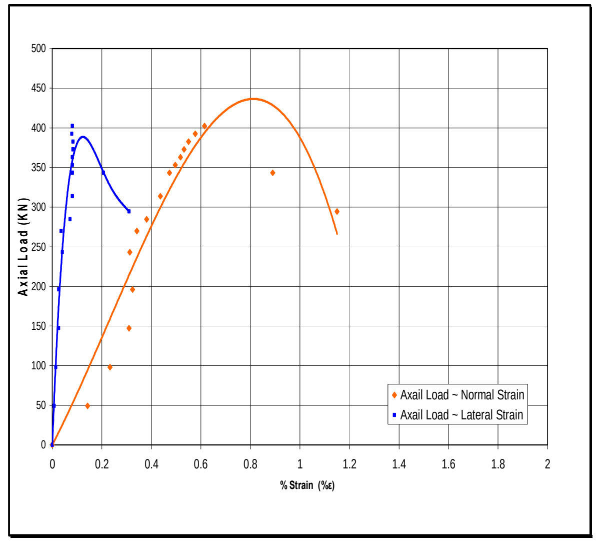

Fig 13: Axial load ~ Column strain curve. For controlled column

Fig 11: LVDTs Installed for Measurements of Horizontal and Vertical Deformations

Figure 14: Failure of control column (CSB1)

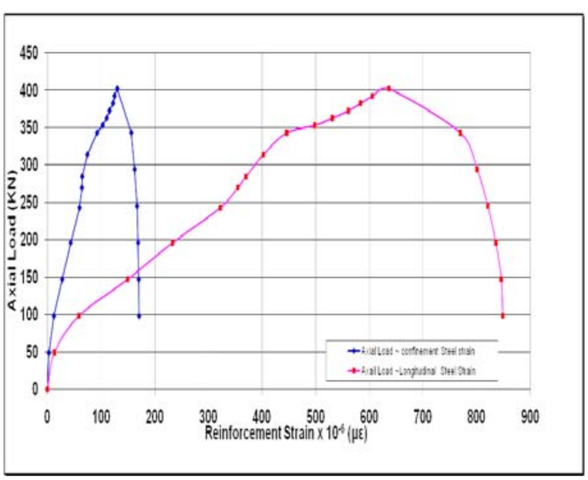

Fig 12: Axial load ~ Steel strain curve for controlled column

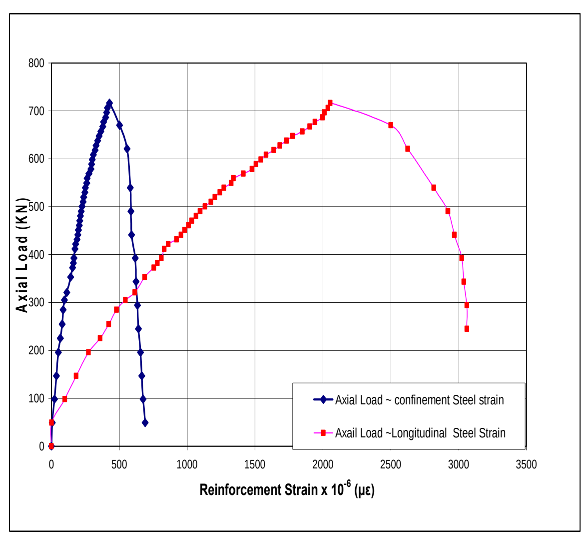

Fig 15: Axial load ~ Steel strain curve, for column confined with 2mm thick strips

3.6 Concrete column confined with 2mm steel strips (CSP1).

Table 2: Controlled Column Results

Sr.#	Axial Load (kN)	Column Strain (%)		Steel strain (με)	
		Axial	Lateral	Main steel	Confining steel
1	0	0	0	0	0
2	49.05	0.14215	0.00720	13	2.904618
3	98.1	0.23315	0.01440	58.59	12.18944
4	147.15	0.34775	0.02633	149.35	27.62828
5	196.2	0.32405	0.02633	233.37	43.20728
6	243	0.31315	0.04073	322.17	59.73464
7	270	0.3168	0.03593	355	64.22364
8	284.49	0.43145	0.07187	370	64.73168
9	313.92	0.436	0.08147	402.32	74.23676
10	343.35	0.4731	0.08147	445.99	92.50081
11	353.16	0.4966	0.08147	498.29	102.9707
12	362.97	0.5175	0.08147	530.92	110.199
13	372.78	0.5322	0.08387	560.66	115.4265
14	382.59	0.550015	0.08387	583.69	122.0471
15	392.4	0.57683	0.07907	605.76	124.7894
16	402.21	0.6151	0.08147	636.94	130.0499
17	343.35	0.89	0.05273	769.79	156.0691
18	294.3	1.15	0.04793	801	162.2697

Table 3: 2mm steel strips column results:

Sr.#	Axial Load (KN)	Column Strain (%)		Steel strain (με)	
		Axial	Lateral	Main steel	Confining steel
1	0	0	0.00000	0	0
2	49.05	0.0036	0.00232	1.93	5.78
3	98.1	0.0026	0.11275	99.18	22.16
4	147.15	0.0018	0.10333	182.94	38.06
5	196.2	0.0046	0.10101	273.42	50.58
6	225.63	0.0076	0.10101	359.07	66.48
7	255.06	0.009	0.10101	423.54	78.53
8	284.49	0.0108	0.10333	479.35	86.72
9	305	0.0126	0.09862	545.24	95.39
10	321	0.01615	0.10101	614.02	113.3
11	353.16	0.01975	0.09630	687.59	142.61
12	372.78	0.01795	0.09862	755.39	156.1
13	382.59	0.03775	0.10804	779.91	161.88
14	392.4	0.02515	0.09630	809.71	166.7
15	412.02	0.01615	0.09862	831.82	173.93

16	421.83	0.02335	0.09391	860.66	177.3
17	431.64	0.03775	0.09630	922.67	188.39
18	441.45	0.03055	0.11036	955.35	193.69
19	451.26	0.04135	0.08688	982.26	198.99
20	461.07	0.03235	0.10101	1011.09	205.25
21	470.88	0.03595	0.09862	1034.16	208.63
22	480.69	0.02875	0.10572	1065.87	213.93
23	490.5	0.03595	0.09391	1096.62	220.19
24	500.31	0.03415	0.09391	1132.17	225.97
25	510.12	0.03955	0.10572	1175.41	233.69
26	519.93	0.04315	0.09391	1204.71	238.02
27	529.74	0.04495	0.09630	1240.73	246.7

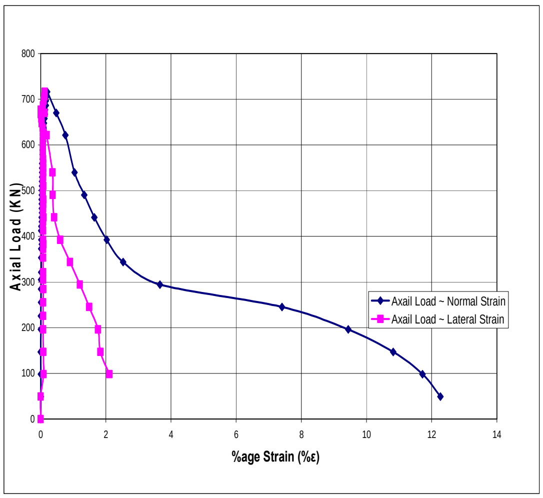

Fig 16: Axial load ~ Column strain curve,

Fig 17: Stepwise Failure of CSP1

5.3 Concrete column confined with 1.2 mm steel strips (CSP2).

Table 4: Column confined with 1.2mm thick strip results.

Sr.#	Axial Load (KN)	Column Strain (%)		Steel strain (με)	
		Axial	Lateral	Main steel	Confining steel
1	0	0	0	0	0
2	49.05	0.058	0.002322	45	1.93
3	98.1	0.1096	0.0034056	96.89	3.87
4	147.15	0.1114	0.003999	148.24	10.15
5	196.2	0.13835	0.0047085	227.19	8.22
6	245.25	0.1743	0.0187695	316.77	12.56
7	294.3	0.22105	0.023478	414.09	19.81
8	343.35	0.2264	0.035217	498.32	35.28
9	362.97	0.3001	0.0422475	563.17	53.16
10	372.78	0.3091	0.035217	600	68.63
11	382.59	0.3001	0.0399255	619.31	73.94

12	392.4	0.3073	0.0422475	640.6	74.91
13	402.21	0.3019	0.0422475	656.09	80.71
14	412.02	0.3055	0.0376035	681.25	80.71
15	421.83	0.32525	0.0258645	707.86	84.58
16	431.64	0.3504	0.0376035	735.44	89.41
17	441.45	0.3756	0.0422475	765.43	94.24
18	451.26	0.44925	0.0399255	795.42	99.56
19	461.07	0.45465	0.0376035	823	104.88
20	465	0.4888	0.0422475	855.89	106.33
21	453.5	0.88	0.0493425	900	135
22	441.45	1.2	0.058695	919.25	165
23	392.4	2.67	0.169119	948	179
24	343.35	3.55	0.3029565	979	201
25	308.6	4.13	0.6200385	1016	206
26	287.2	4.64	0.7726455	1040	224

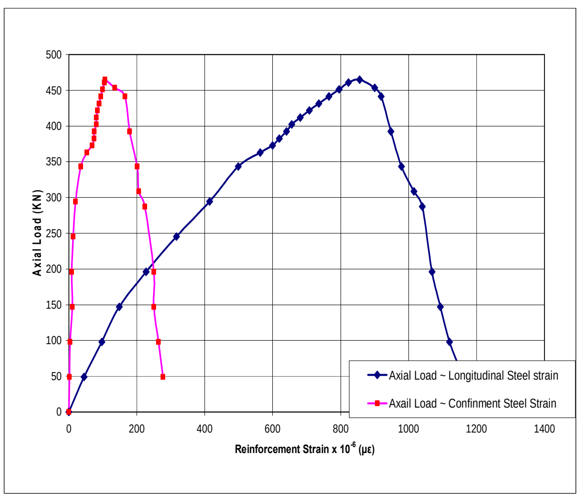

Fig 18: Axial load ~ Steel strain curve, for column confined by 1.2mm thick strips

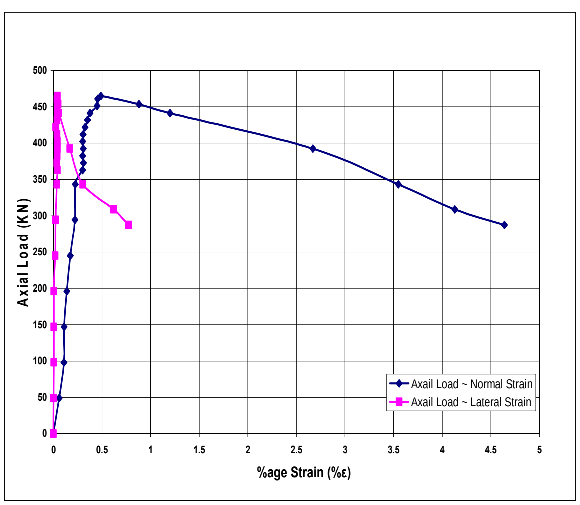

Fig 19: Axial load ~ Column strain curve, for column confined by 1.2mm thick strips

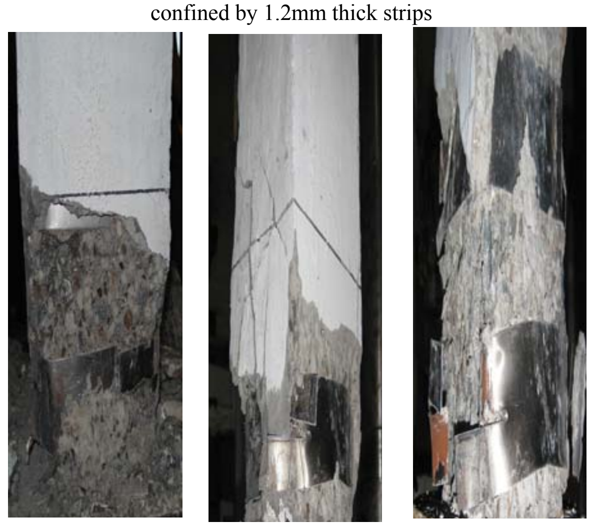

Fig 20: Failure of CSP2

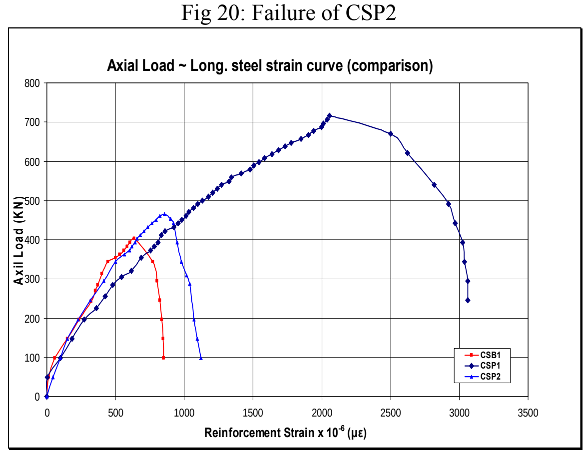

Fig 21: Axial load ~ Longitudinal Steel strain curve, comparison of CSB1, CSP1 & CSP2

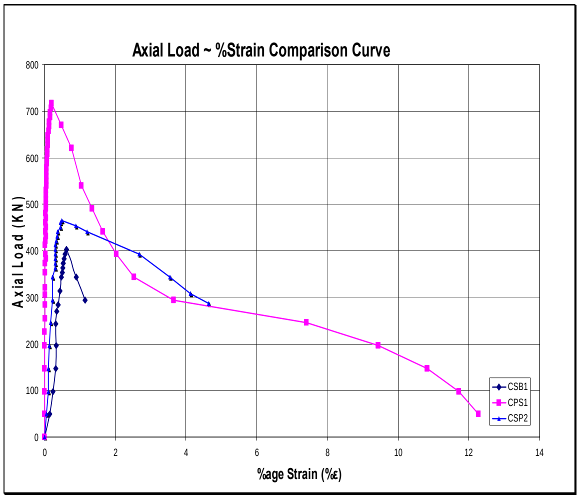

Fig 22: Axial load ~ Column strain curve, comparison of CSB1, CSP1 & CSP2

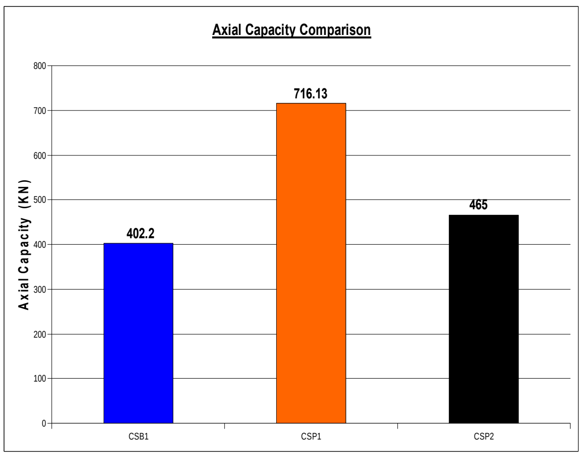

Fig 23: Axial capacity comparison chart, comparison of CSB1, CSP1 & CSP2

4. CONCLUSIONS:

The comparison of three columns including controlled columns investigation results. The following conclusions are drawn from the study.

- Control column (CSB1) showed less deformability as compared to other columns. It failed at ε_{cl} = 1.15% after peak load, longitudinal bars bow out-word and concrete core crushed suddenly.
- Significant improvement has been recorded for 2mm x 36 mm confining strip (Used in CSP1) in large strength having P_u = 716.13 kN and ductile behavior with ε_{cl} = 12.4%
- Axial capacity of Column confined with 2 mm steel strips was approximately 78% more as compared to control column and column confined with 1.2 mm steel strips showed only 15.8 % greater capacity relative to CSB1 as shown in Fig. 22.
- 1.2 x 60 mm confining strips used in CSP2 were not able to resist the bulging of concrete core due to inadequate stiffness, that is the reason the capacity of CSP2 is less than that of CSP1. However, it is more than that of CSB1.
- Deformability (toughness) of concrete tied column can be improved by replacing the circular tie bar with equivalent area steel plate.
- The peak strength and the corresponding strain of confined concrete could be affected by the configuration and shape of lateral confinement.
-

5. REFERENCES:

1. ACI Committee 318, Building Code Requirement for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05) American Concrete Institute, Farmington Hills, MI, 2005
2. Cusson and P Paultre, High-strength concrete columns confined by rectangular ties, *Journal of Structural Engineering ASCE*, **120**(3), pp. 783–804(1994).
3. P.Paultre and F.Legron, Confinement reinforcement design for reinforced concrete columns, *Journal of structural engineering ASCE* , 0733 **(05)**, pp. 738-749(2008).
4. Saatciogler, M. and Baingo, D., Circular high-strength concrete columns under simulated seismic loading, *Journal of structural engineering*, **(03)**, pp. 273-280(1991).
5. Watson, S. and Parker, R., Simulated seismic load tests on reinforced concrete columns, *Journal of Engineering and Management*, **(6)**, pp. 1825-1849(1994).
6. Mander, J.B., Priestly, M.J.N., and Park, R., *Seismic design of bridge piers,* Rep. No. 84-2, University of Canterbury, New Zealand(1994)..
7. Shafqat A**.,** Effect of lateral confinement on compressive strength of RC short columns, *MSc research thesis*, University of engineering and technology Lahore, 2008.
8. B Li, R Park and H. Tanaka, Stress–strain behavior of high-strength concrete confined by ultra-high- and normal-strength transverse reinforcements, ACI *Structural Journal*, **98** (3), pp. 395–406(2001).
9. Macgregor, J.G., Reinforced Concrete, - *Mechanics and Design*, 3rd ed, 1997, Prentice Hall, upper Saddle River, NJ, 07458