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The Performance of Self-Compacted High Strength Concrete Columns with Laced Steel Section

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Abstract

In view of the great orientation to the steel buildings and the large role played by the columns in carrying and transferring the loads it is necessary to go to strengthen the steel rolled columns to meet the requirements of the architecture that witch is looking for large spacing. In present paper this research the objectives of this research can be summarized as following: prevent local buckling occurs in columns, strengthen the steel columns from the weak axis in a new methodology, to compare buckling loads of single lacing reinforcement versus double lacing reinforcement and obtain a high bearing column steel section with small surface area increase in column strength capacity. Different parameters are taking into account to investigate the behavior and strength of steel and composite columns such as slenderness ratio, and double lacings and presence of longitudinal reinforcement that parallel to the column height. The type of concrete that adopt is self-compact concrete with high compressive strength. The new and alternative method is were used to strengthen the steel rolled columns at low cost by strengthening the weak axis to preventing or minimize buckling of the columns by using high strength concrete self-compacted without main reinforcements with steel section columns reinforced by lacing as single and double so that it work as full composite structural element and there are connections between concrete block and steel column. There are five specimens with the same height of 1450 mm that was classified as the control specimen and the others with different parameters such as lacing configurations, presence of longitudinal dowels and presence of concrete subject to concentric load. All specimens except the control filled with self-compacted high strength concrete. The result showed that as increase in strength in presence of concrete as compared with the control specimen. Control specimen gave strength capacity compared with the others composite specimens; the increased are 50% composite column, 62.50% composite column with single lacing and 75.00% composite column with double lacing respectively. Specimen (CL1CDL2R) increased in strength capacity as compared with the control specimen 87.50% and 7.14% compared with specimen (CL1CDL) because of presence dowels along the specimen height that increase the stiffness of the composite column. Presence of single and double lacing reduced the buckling value because of reduced the effective columns height. Specimen (CC1L1) gave maximum buckling 32.00 mm compared with the others specimens such as CL1C), (CL1CSL), (CL1CDL) and (CL1CDL2R) respectively, there is significant difference in buckling that reduced by 17.19%, 28.13%, 45.31% and 55.63% respectively.

Keywords: Column Strengthens; Lacing; Self Compacted Concrete; High Strength Concrete; Composite Columns.

1. Introduction

Columns are structural members subjected to combinations of axial compression and bending moment, rather than pure axial loading so that this structural element is they are of critical of importance for the performance and safety of structures. In spite of the importance of columns in the buildings, they don't constitute more than 2% of the total weight of the building, so strengthening columns are more important and essential to ensure the safety of building and make

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sure to bear the worst conditions that any building can be exposed [1]. There are many ways to strengthen the columns but through this research, I looked for alternative ways to strengthen the steel section columns. Using one of the types of reinforcement of the steel section by using lacing reinforcement in addition self-compacted high strength concrete has been used to ensure higher capacity and to ensure that concrete get below and above of lacing reinforcement bar. The research consist of five specimen with the same length 1450 mm tested under the same condition concentric loading, but there is difference in characteristics for each of them. One of them was used only concrete for strengthen it from the weak axis and the other one used single lacing reinforcement else double lacing reinforcement all of them filled with self-compacted high strength concrete except the control one which was steel section only.

Anandavalli et al. [2] proposed a new method for displaying reinforced concrete structures which has been adopted to analyze a BLRC structures. "The approach assumed RC/LRC as a homogenous material, whose constitutive property is derived based on the moment-curvature relationship of the structural component. An equivalent SDOF system obtained based on proven technique is analysed to verify the results of the FEA. Current approach significantly decreases the modelling effort and in turn, the computational demand for a given accuracy in the result" The available methods for represent the reinforcement in a Finite Element model of Reinforced Concrete structures can be collected under 3 styles. There are discrete model, smeared model, and embedded model. In smeared model approach, can modelled reinforcements as a layer of similar thickness. This is suitable for modelling structures, with a uniform reinforcement distribution. embedded or Discrete model approach has to be take on when the reinforcement consists of different bars sizes or when they are at irregular spacing. At Discrete model approach the modelling of reinforcement by bars elements with added .common nodes for steel and concrete. This needs the concrete to be separate affording to the reinforcement pattern. If extensive reinforcement detailing was used, then this approach becomes uninteresting and eats time. In embedded model approach, the reinforcement grate is entrenched in concrete. In this approach, concrete discretization wants to match with the reinforcement has to be demonstrated using one dimensional FA.

Allawi and Arshad [3] studied the Response of Laced Reinforced Concrete Beams subjected to Repeated Loading In this research, the structural behavior of Laced Reinforced Concrete T-beam of cross sectional dimensions (300 × 80 mm) flange and (150 × 220 mm) web under monotonic loadings was studied experimentally. Two types of lacing reinforcement with inclination angle of 45° and 60° with respect to the longitudinal reinforcement and 6 and 8 mm diameters for each type were used. During monotonic loading tests, the load deflection values at different locations of the tested specimens were recorded in addition to determination of the ultimate load. Also, the support rotation and the ductility ratio for each tested beam were calculated. The study of inclination angle of lacing reinforcement shows that lacing reinforcement of 60°, inclination angle has more deflection than that of 45°, inclination angle, also the ultimate load of first type above is more about 6% than other type. The results show that beams with lacing reinforcement are stiffer than beams with conventional stirrup reinforcement. Results have shown that specimens with lacing reinforcement are more ductile than beams without lacing (conventional vertical stirrups) and the ductility factor of laced reinforced beams ranges from 1.73 to 11.7, while it is 1.6 for unlaced (stirrups) beams. Also, the support rotation of laced reinforced concrete beams is about five times higher than that of conventional reinforcement.

In another research Allawi and Jabber [4] studied Experimental Behavior of Laced Reinforced Concrete One Way Slab under Static Load the Test results of eight reinforced concrete one way slab with lacing reinforcement are reported. The tests were designed to study the effect of the lacing reinforcement on the flexural behavior of one way slabs. The test parameters were the lacing steel ratio, flexural steel ratio and span to the effective depth ratio. One specimen had no lacing reinforcement and the remaining seven had various percentages of lacing and flexural steel ratios. All specimens were cast with normal density concrete of approximately 30 MPa compressive strength. The specimens were tested under two equal line loads applied statically at a thirds part (four point bending test) up to failure. Three percentage of lacing and flexural steel ratios were used: 0.0025, 0.0045 and 0.0065. Three values of span to effective depth ratio by 11, 13, and 16 were considered, the specimens showed an enhanced in ultimate load capacity ranged between 56.52% and 103.57% as a result of increasing the lacing steel ratio to 0.0065 and decreasing the span to effective depth ratio by 31.25% respectively with respect to the control specimen. Additionally the using of lacing steel reinforcement leads to significant improvements in ductility by about 91.34% with increasing the lacing steel ratio to 0.0025 with respect to the specimen without lacing reinforcement.

Anandavalli et al. [5] proposed a new method for displaying reinforced concrete structures which has been adopted to analyze a BLRC structures. "The approach assumed RC/LRC as a homogenous material, whose constitutive property is derived based on the moment-curvature relationship of the structural component. An equivalent SDOF system obtained based on proven technique is analysed to verify the results of the FEA. Current approach significantly decreases the modelling effort and in turn, the computational demand for a given accuracy in the result. LRC behavior and its use for blast resistant design has been chatted in detail by Lakshmanan [6] reaction of LRC beam under small shear, (L/d) % also exists. It was also detected that static ductility is significantly higher than cyclic ductility for these beams. Inclusion of fibers was found to increase the performance substantially under reversed shear cyclic loading. The versatility of LRC under blast loading was demonstrated by full scale testing. Allawi and Shubber [7] studied the behavior of laced reinforced concrete beam under static Load. They tested five laced reinforced concrete T-beams of cross sectional dimensions 300 × 80 mm flange and 150 × 220 mm web with different lacing angles. Test results indicated that. The lacing reinforcement of 60° inclination angle with respect to longitudinal reinforcement has more stiffness, i.e., less deflection than lacing reinforcement of 45° inclination angle with respect to longitudinal reinforcement.

2. Methodology

All five specimens before applied loading were lifted into the test machine without any eccentricity. All columns specimens tested under monotonically increasing concentric loading by a hydraulic jack. Strain gauges were connected to data acquisition system (data logger) in specific locations. Three dial gauges were placed on concrete surface at quarter, middle, and three quarters of the column height to measure the lateral deformations. Two dial gauges were placed at the middle on the steel side to measure the lateral deformation (buckling) in compression and tension zone. Lacing reinforcement of 6 mm diameter deformed bar placed that make 45˚ inclination angle with longitudinal main diagonal. The detailed explanations have been lists Table 1.

Table 1. Column used in experimental work

Column symbol	Type of reinforcement	Status
CCL1	None	Steel section only
CL1C	None	Steel section plus concrete
CL1CSL	Single lacing	Steel section plus concrete plus single lacing two sides
CL1CDL	Double lacing	Steel section plus concrete plus double lacing two sides
CL1CDL2R	Double lacing with longitudinal reinforcement	Steel section plus concrete plus double lacing two sides with dowels

In which:

CC: column control

L1: Column length (1450 mm)

C: Concrete

SL: Single Lacing Reinforcement

DL: Double Lacing Reinforcement

2R: two longitudinal rebar

2.1. Details of the Column Specimen

The steel section has been used all the five specimens with total depth 140 mm, flange width 980 mm flange thickness 7.5 mm, web depth 125 mm and web thickness 5 mm have yielding tensile strength 275 MPa and modulus of elasticity 200 GPa. All specimens have the same length of 1450 mm. The specimens details lists in Table 1.

2.2. Fabrication of Lacing Reinforcement

Deformed steel bar of diameter 6 mm were used in fabricated of lacing reinforcement. The fabrication and construction of laced reinforcement to the required shape and dimension have been done by universal press machine in industrial as shown in Figure 1.

Figure 1. Lacing reinforcement Fabrication

3. Material

All row materials that adopted are local materials such as reinforcement, cement, fine and course aggregates.

3.1. Steel Reinforcement

For longitudinal and lacing reinforcement, deformed steel bar of diameter 6 mm have been used. Three specimens of 500 mm length for deformed bar have been tested in the consulting engineering Bureau/ college of Engineering / University of Baghdad. The test results lists in Table 2.

Table 2. Mechanical properties of steel reinforcement

Nominal diameter deformed (mm)	Measured diameter (mm)	Yield stress f_y (MPa)	Tensile strength f_u (MPa)	Elongation (%)
6	**6**	415	574	5

3.2. Cement

For all test specimens Ordinary Portland cement of (mass) brand, the result of chemical analysis and physical test are conformed to the Iraqi specifications No.5/1984. The tests were conducted by the national center of laboratories and researches.

3.3. Fine Aggregate

Natural sand of Wellayet Ali factory in Al-Najef governorate was used for concrete mixes in this study. The fine aggregate has 4.75 mm maximum size. The results of Sieve analysis was obtained indicated that the sand grading was within the Iraqi specifications No.45/1984.

Table 3. Grading of the fine aggregate

Sieve Size (mm)	% Passing by Weight	Iraqi Specification, No.31, 1981
9.5	100	100
4.75	100	95-100
1.18	75	45-80
----	----	----
0.30	29	10-30
0.15	5.5	2-10
0.075	1.2	3

Table 4. Physical properties of the fine aggregate

No.	Physical Properties	Test Result	Iraqi Specification, No.31, 1981
1	Specific gravity	2.63	----
2	Sulfate contained %	0.123	0.5

3.4. Course Aggregate

Graded Crushed gravel of 10 mm maximum size from Al-Nibaee region was used. The crushed gravel coarse aggregates were washed and stored in air to dry the surface. The results of Sieve analysis was obtained indicated that the sand grading was within the Iraqi specifications No.45/1984.

Table 5. Grading of the course aggregate

Sieve Size (mm)	% Passing by Weight	Iraqi Specification, No.31, 1981
37.5	100	100
19	100	95-100
14	----	----
9.5	36	20-55
4.75	1.5	0-10
2.36	----	----
0.075	0.1	1.0 (max)

Table 6. Physical properties of the coarse aggregate

No.	Physical Properties	Test Result	Iraqi Specification, No.31, 1981
1	Specific gravity	2.63	----
2	Sulfate contained %	0.123	0.25 (max)

3.5. Super Plasticizer

Sika viscocrete-5930 is a third generation superplasticizer for concrete and mortar. It meets the requirements for super plasticizer according to ASTM-C-494 type G and F and BS EN-934-part2-2001. It is suitable for production of concrete and it is facilitates extreme water reduction, excellent flow ability at the same optimal cohesion and highest self-compacting behavior. The properties of the super plasticizer are shown in Table 7.

Table 7. Properties of superplasticizer

Basis	Aqueous solution of modified poly carboxylate
Appearance	Turbid liquid
Density	1.08kg/lt ±0.005
Packaging	5, 20 Kg pails 200 kg drums
Storage/Shelf Life	In unopened, undamaged original container protected from direct sun light and frost at temperatures between +5˚C and +35˚C. Shelf life at least 12 months from date of production.
Dosage	For soft plastic concrete:0.2-0.8%litre by weight of cement For flowing and self-compacting concrete(S.C.C.) 0.8-2% litre by weight of cement
Frozen	It is may be used after it has been slowly thawed at room temperature and intensively mixed.
Safety Precautions	In contact with skin, wash off with soap & water. In contact with eyes or mucous membrane, seek medical attention without delay.

3.6. Water

Tap water was used for casting and curing in all the specimens.

4. Properties of Fresh Self-Compact Concrete (SCC)

The main characteristics of SCC are the properties in the fresh state. SCC mix design is focused on the ability to flow under its own weight without vibration, the ability to flow through heavily congested reinforcement under its own weight, and the ability to obtain homogeneity without segregation of aggregates.

4.1. Slump Flow Test

The slump cone has been lifted and the specimen has collapsed, the diameter of the spread is measured rather than the vertical distance of the collapse as shown in Figure 2. The average of the diameter of flowing is 690 mm which is within the limits set by EFNARC (600-850 mm) [8].

Figure 2. Slump flow test measurement

4.2. T50 Test

A test method for evaluating the rate filling of SCC, where the 500 mm flow reach time is measured in the slump flow test above is 3 seconds that within range of 2-5 [10].

4.3. L-Box Test

The passing ability is determined using the L-box test as shown in Figure 3. The vertical section of the L-Box is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. The height of concrete at the end of the horizontal section is expressed as proportion of that reaming in the vertical section. The test result is 1.0 within range of ratio between the heights of the concrete at each end or blocking ration to be 0.8-1.0.

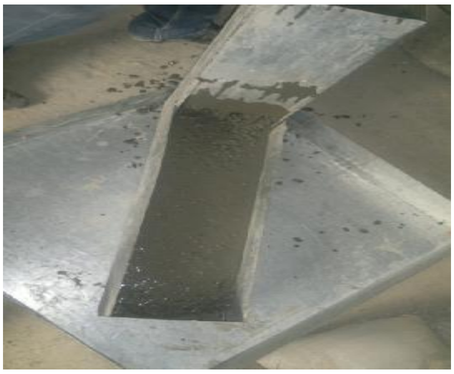

Figure 3. L-Box test

4.4. V- Test

A test method for evaluating both the filling ability and material segregation resistance of SCC, using a funnel, as shown in Figure 4, where the efflux time of SCC with course aggregates having the maximum size 10 mm diameter is measured. The flow time for all of the concrete to exit the funnel is recorded as a measure of filling ability. The flow time was 6 seconds which is less than 10 seconds. To measure segregation resistance, the V-funnel is refilled with concrete and allowed to site for 5 minutes. The door is again opened and flow time is recorded. The greater increase in flow time after the concrete has remained at rest for five minutes, the greater will be the concretes susceptibility to segregation. Further, non-uniform flow of concrete form the funnel suggests a lack of segregation resistance [9]. The time recorded was 10 seconds in the second phase and the flowing is uniform that mean the segregation is not expected to happen.

Figure 4. V-Funnel test

4.5. Design Mix

The design mix was satisfying the specification of fresh properties and to match the compressive strength limits adopted. Many trial mixes were carried out to obtain the required compressive strength of SCC. Super plasticizer 1.5% by weight of cement was added to the mix to increase the workability of concrete. Details of mix are given in the following Table 8.

Table 8. details of trial mix

Mix Ratio by weight	W/C	Water (Liter)	Cement (Kg)	Sand (Kg)	Gravel (Kg)
1:1.21:1.8	0.2	10	50	61	90

5. Test Methodology

A hydraulic test machine with capacity of 150 ton used to test the sample and the tests results as ultimate load capacity and lateral deformations for all specimens are recorded and plotted below.

Figure 5. Test Machine

6. Result

6.1. Load - Lateral Deformation (Buckling) Relationship

The lateral deformation due to applied loadings lateral deformation (buckling) have been measured at quarter, mid, and three – quarter of the columns height. The load lateral deformation (buckling) curves have been plotted for each tested column, as shown in Figure 6. The maximum lateral deformation obtained is (32 mm) corresponding to ultimate load (400 kN) for specimen CCL1.

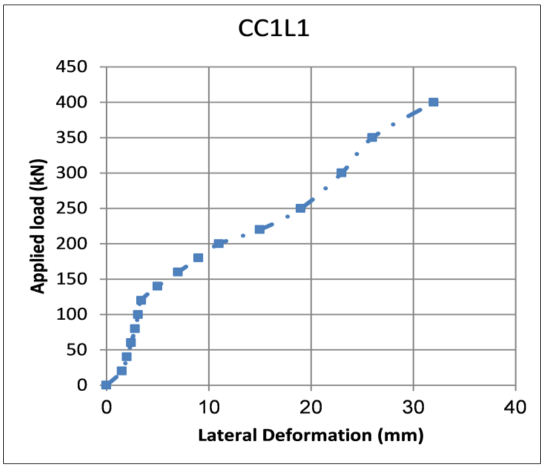

Figure 6.a. Load-lateral deformation (buckling) for specimen1

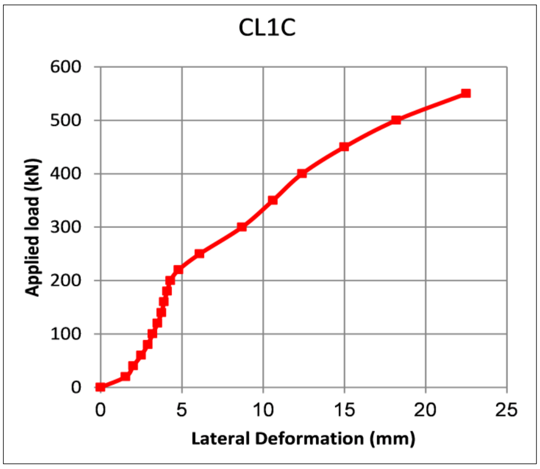

Figure 6.b. Load-lateral deformation (buckling) for specimen 2

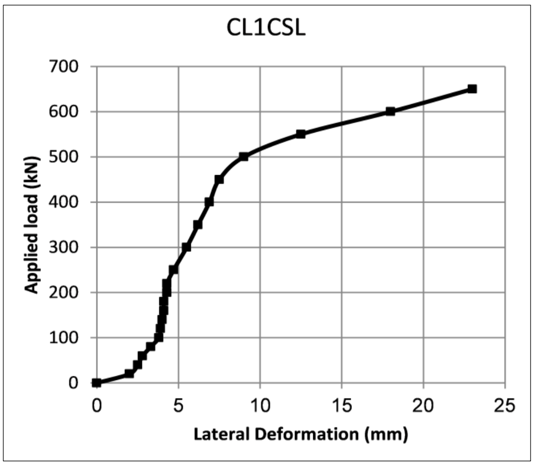

Figure 6.c. Load-lateral deformation (buckling) for specimen 3

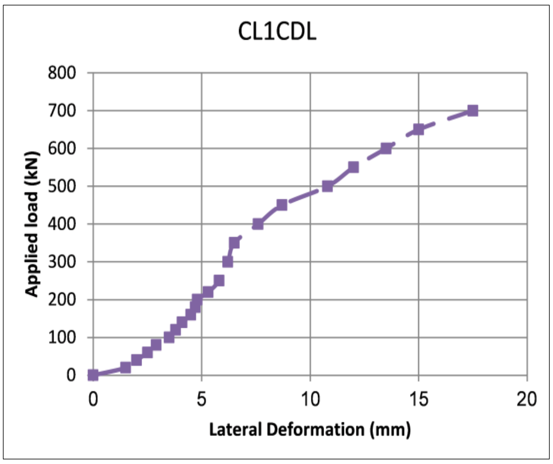

Figure 6.d. Load-lateral deformation (buckling) for specimen 4

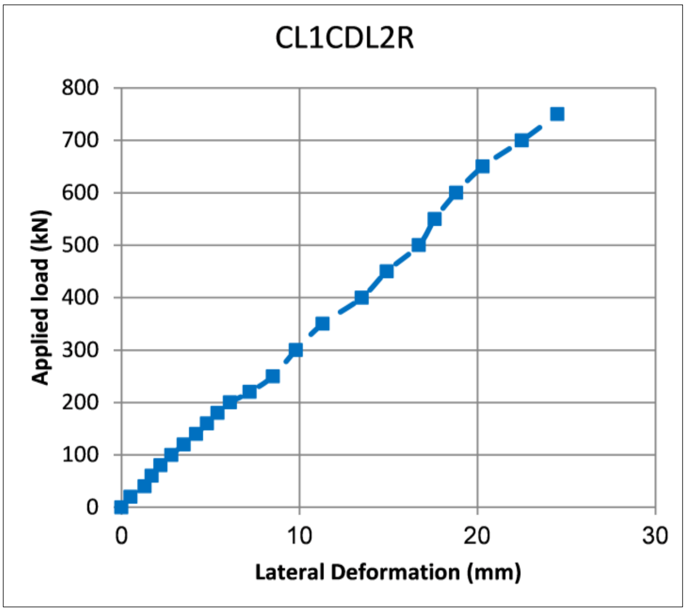

Figure 6.e. Load-lateral deformation (buckling) for specimen 5

The load versus mid span lateral deformation (buckling) for all five tested columns has been plotted in Figure 6.

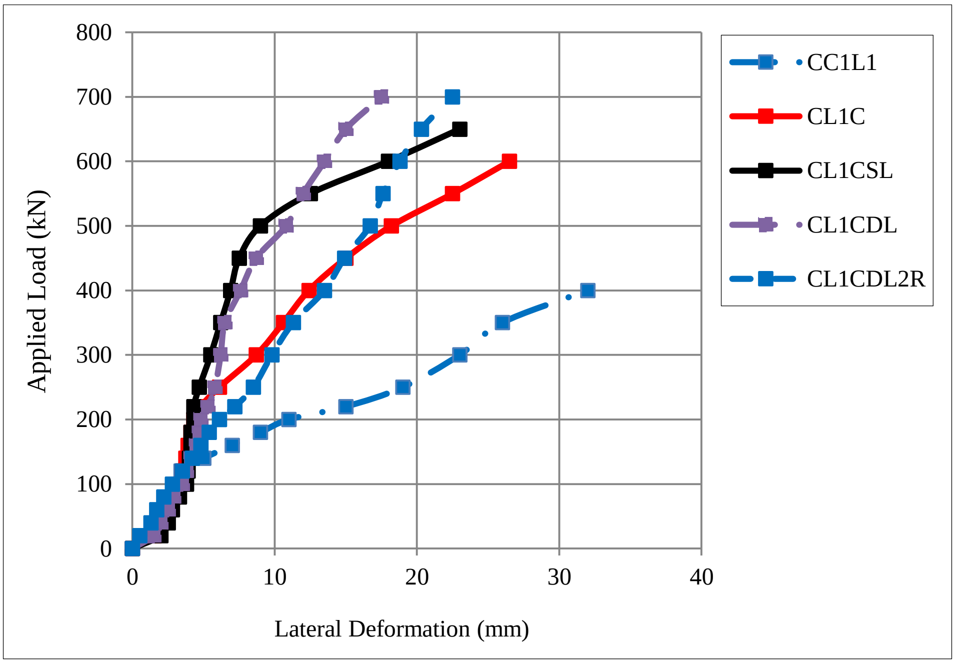

Figure 7. Load-lateral deformation (buckling) for all specimens

From Figure 7, column CC1L1 has larger lateral deformation than other specimens, specimen CL1C has reduce in lateral lateral deformation (buckling) percentage 17.18%, as comparative with the control specimen CC1L1, specimen CL1CSL has 39.13%, reduction in lateral deformation as comparative with control specimen, column CL1CDL also has a reduction in its lateral deformation by 45.31%, and specimen CL1CDL2R has reduce the lateral deformation by 23.43%. Table 5 lists the ultimate loads for each specimen with corresponding lateral deformation.

Table 5. Details of Final Test Results

Specimen mark	Ultimate load (kN)	Lateral deformation (mm)
CCL1	400	32.0
CL1C	520	26.5
CL1CSL	640	23.0
CL1CDL	700	17.5
CL1CDL2R	710	24.5

6.2. Lateral Deformation Profile

Deformation profile (buckling) for all specimens has been plotted according to dial gauges stilled at quarter half, and three quarter of the span for each specimen, Figure 8 show the full behaviour of the lateral deformation for all specimens. The laterals deformations at the ended top and bottom zero because of at the supports boundary condones. The maximum lateral deformations occur at the middle height of each column. The relationship along the column height is nonlinear deformation. The maximum deformation at the one-quarter and three-The maximum buckling occur in the control specimen (steel section) without lacings and block concrete

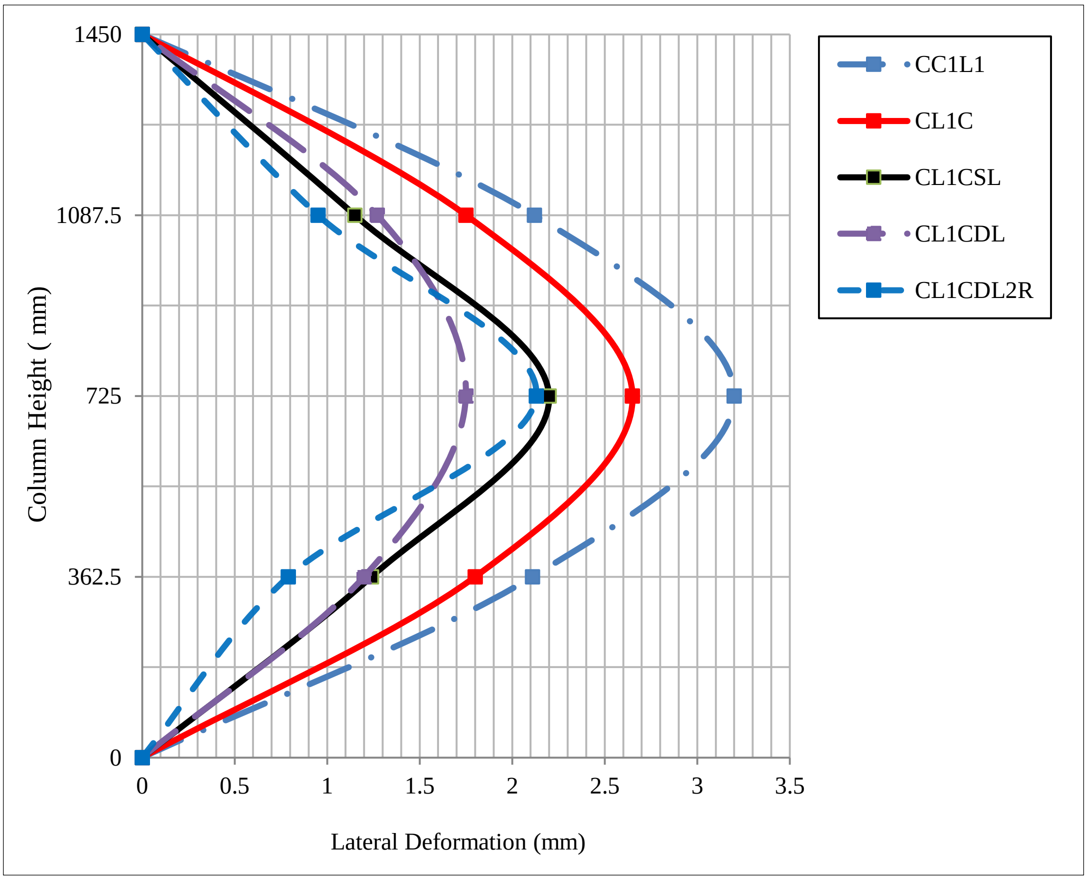

Figure 8. Lateral-deformation for all specimens

6.3. Mode Failure

As the tested specimens reached its failure load, the specimen CCL1 failure by flange local buckling , CL1C concrete crushing and no local buckling occurs specially in the web, specimen CL1CSL concrete crushing and small global buckling occurs and lacing bar has been curvature, specimen CL1CDL concrete crushing ,small global buckling occurs and curvature of lacing bar was clearly appeared, specimen CL1CDL2R is behaviour like specimen CL1CDL with increasing by strength and cracks which mean that the longitudinal bar has been contributed more with lacing bars. In case of I section similar that tested here (open cross section) in which this type have low torsional stiffness that lead to the tested specimens such as the specimen (CC1L1) have torsional buckling. In case of composite columns such as other specimens have high torsional stiffness because of presence of concrete blocks that gave more lateral support.

The concrete block increased in shear modulus and polar moment of inertia that lead to resists the torsional buckling. The behaviour of steel and composite columns as lateral buckling due to applied axial loading are investigated. The buckling represent as a mathematical model to calculate the instability that cause failure of the steel or composite columns. In the experimental work, the axial applied force was compressive so that developed axial compressive stress in tested specimens. The lateral buckling based on the magnitude of the sideways deflection of the steel or composite columns specimens under the effects of applied compressive loadings during tests. Specimens as steel columns (CC1L1) showed that as the load increased, caused the column to become unstable because of there were increased in lateral deformations and become 32.00 mm for control specimen. In case of composite columns, the deformations are less than of the steel columns specimens because of the presence of concrete. The concrete block gave more stability to the composite columns because of increased in moment of inertia and equivalent modulus of elasticity of composite columns (increased in stiffness). The buckling mode of deformation is considered a failure mode which occurs for specimens before the axial compression stresses (direct compression) that caused failure of the material by yielding of steel section or crush of those composite columns. All mode of failure are shown in Figure 9 to 17.

Figure 9. Failure mode all five specimens

Figure 10. Lacing Bar curvature Specimen CL1CSL

Figure 11. Concrete Crushing specimen CL1CSL front view

Figure 12. Failure mode of Specimen CL1CSL side view

Figure 13. Failure mode of Specimen CL1CDL2R front view

Figure 14. Failure mode of Specimen CL1CDL2R Back view

Figure 15. Concrete Crushing specimen CL1CDL front view

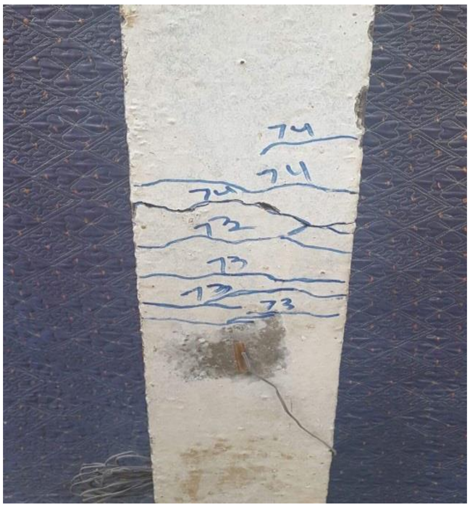

Figure 16. Concrete Crushing specimen CL1CDL Back

Figure 17. Failure mode of Specimen CC1L1 side view

7. Conclusion

Based on the results from experimental tests, the strength capacity, lateral deformation, mode of failure, local buckling of steel and composite columns is discussed. Single and double lancing not contribute to increase the strength capacity of both steel and composite columns because of the function of lacing to resists lateral force not axial force. Control specimen (CC1L1) gave strength capacity 400 kN, compared with the others specimens such as (CL1C), (CL1CSL) and (CL1CDL) the increased are 50%), 62.50% and 75.00% respectively. Specimen (CL1CDL2R) increased in strength capacity as compared with the control specimen 87.50% and 7.14% compared with specimen (CL1CDL) because of presence dowels along the specimen height that increase the stiffness of the composite column. Presence of concrete block gave the composite columns higher strength capacity than steel column because of increased in stiffness of composite columns due to increase in moment of inertia and modulus of elasticity. Presence of single and double lacing reduced the buckling value because of reduced the effective columns height.

Specimen (CC1L1) gave maximum buckling 32.00 mm compared with the others specimens such as CL1C), (CL1CSL), (CL1CDL) and (CL1CDL2R) respectively, there is significant difference in buckling that reduced by 17.19%, 28.13%, 45.31% and 55.63% respectively. Concrete block gave the composite column less buckling because of provides lateral resistance. Test results showed that increasing in the strength capacity of composite column specimens as compared with the control specimen (CC1L1) because of the presence of concrete gave more worked as composite structural element that increased in modulus of elasticity and moment of inertial that lead to increase in lateral restraint and prevent column buckling, so that the critical load increased. From the test results lateral deformation decreasing in presence of concrete block because of the whole section worked as full interaction composite column. Self-compacting concrete was of big use by increasing the ability to flow through heavily congested reinforcement under its own weight without need to vibrating and decreasing the probability of segregation.

8. Conflicts of Interest

The authors declare no conflict of interest.

9. References

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