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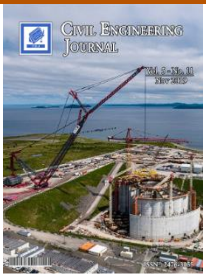
Civil Engineering Journal

Vol. 5, No. 11, November, 2019



Study on Retrofitting of RC Column Using Ferrocement Full and Strip Wrapping

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Received 07 July 2019; Accepted 11 October 2019

Abstract

Ferrocement is one of the cement-based composites used for retrofitting and rehabilitation among many applications. Ferrocement is one of the reinforced concrete form with lightweight and thin composite with durability and environmental resistant that strengthen the conventional RC columns to increase its strength and serviceability. This paper examines the performance of the ferrocement wrapping in RC columns experimentally with numerical simulation using ANSYS19. Totally sixteen number of RC column of size 150 mm × 150 mm in cross section and 450 mm in length were cast and tested in laboratory. Twelve are retrofitted columns with respect to volume fraction and wrapping technique. Six columns were retrofitted by full wrapping technique and six columns of strip wrapping technique. The remaining four columns are control columns in virgin condition to compare with the retrofitted columns. Concerning the volume fraction of each specimen, the number of pre-woven mesh layers were single layer, double layer and three layers. C30 concrete grade adopted in all specimens as per ACI Committee 211-1.91 with 4H8 longitudinal reinforcement and H6 of 75mm c/c ties. As the previous researchers examined the ferrocement and proved its efficiency. This study aims to examine the ferrocement in full and strip wrapping technique to compare their efficiency to increase the strength. Finite element analysis using ANSYS19 adopted to compare the experimental data with the numerical simulation. The results are analyzed and observed that the ferrocement has increased the confinement and strength of the RC columns.

Keywords: Ferrocement; Reinforced Concrete Column; Full Wrapping; Strip Wrapping; ANSYS.

1. Introduction

1.1. Retrofitting

Generally, the retrofitting term indicates or refers to a new technology, system, or feature added to an older existing system in which it affects its properties and efficiency positively. This term retrofitting is common in the built and construction sectors, in which this technique is used in the strengthening and repairing of old structural members and finally achieving load enhancement. Also, used for the protection against the earthquakes. The retrofitting is categorized into two techniques global and local. The global technique of the retrofitting is completed by adding wing walls, shear walls, infill walls, wall thickening, mass reduction, bracing, and base isolation. The seismic retrofitting method using elastoplastic steel dampers at an existing reinforced concrete building is an effective method since the conventional

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http://dx.doi.org/10.28991/cej-2019-03091425

retrofitting methods like installing shear walls or adding steel frame bracing are not satisfactory and have many problems [1]. The local retrofitting techniques are including the jacketing of beams, jacketing of columns, jacketing of joints, and jacketing of individual footings. The jacketing done using different materials such as Fiber reinforced polymer (FRP) in which it can be GFRP, CFRP, and Aramid, Ferrocement, PVC, etc. In other words, the local retrofitting mainly depends on the composite materials like polymer-based composites, resin-based composite, cement-based composite, and plate-based composite. There are many advantages of applying the retrofitting technique such as utilizing the existing materials and new technologies, reduces the cost of maintenance and helps in preventing the start over of the existing structures.

Many retrofitting techniques are available and widely used like jacketing of the elements, and the most popular technique of jacketing is fiber-reinforced polymer jacketing that is of high in cost when applied [2]. Each technique has its own advantages and disadvantages such that one of the challenges in strengthening by FBR is the brittle behavior that leads to the early de-bonding between the FBR and the reinforced concrete columns, thus the FBR is fastened mechanically with the RC column by steel anchors that will increase their bonding and reduce the action of early de-bonding that increased the ultimate load lateral load of the strengthened column by 37% [3]. The researchers investigated an alternative local technique for retrofitting such as ferrocement. The columns are the most important members to transfer the load to the foundation. Also, by the increase of the population, the demand for adding new stories to existing buildings has increased. Such that the capacity of the column must meet the additional load requirement to avoid collapses in the future [4]. There are many retrofitting techniques for the deficient columns and the one that exposed to seismic behaviour such that it is the retrofitted by two techniques either by retrofitting of the entire height of the column or repairing the damaged localized section [5].

1.2. Ferrocement

The ferrocement is a term published by its inventor Joseph Monier, a French engineer at 1875's. The ferrocement is one of the cement-based composites in which it is a local retrofitting technique. The ferrocement is a thin wall which is about 2 - 3 cm thickness constructed by a cement-sand mortar and reinforced with a closely spaced metal or other suitable mesh in layers pattern. There are many shapes and sizes like square woven wire mesh, expanded metal lath, square welded wire mesh, and hexagonal wire mesh. This composite can be used in different sectors, for marine applications in boat construction, in agricultural in which is used for pipes, shells for fish and poultry farms, canal linings, and grain storage bins. In water supply and sanitation field, ferrocement used such in the construction of water tanks, sedimentations tanks, well casings, septic tanks and swimming pool linings. Also, it used in residential buildings and renewable energy sectors for different purposes.

This composite has many advantages such as the required raw materials are available in the local markets, it can be fabricated into any shape without needing significant formwork, and unskilled labours can be hired to complete the work. The ferrocement composite also has more features, like the lightweight, it is high strength and stiffness composite. Ferrocement also has fire, and corrosion resistance as well as the ability of energy absorption. The strength of the ferrocement depends on cement-sand mortar mix proportion and the volume fraction of the mesh. Due to the feature and the advantages of the ferrocement composite, it can be adopted as an effective retrofitting material [6]. The ferrocement is a good repairing material that carries advantageous properties to strengthen an existing reinforced concrete member after exposing to physical destruction or chemical attack. Such that the ferrocement can withstand any thermal changes and acts as a waterproofing without any surface treatment using any chemicals [7].

According to the literature, the square-shaped columns give more ability to carry out the axial compression load over the circular column and the reference columns, considering the slenderness ratio. Adopting wire mesh to form the ferrocement layers as a reinforcement is an effective technique to increase the load carrying capacity of the column [8]. Effective confinement of concrete in a column using square ferrocement jacketing cannot be provided by single or double layers of mesh and mortar only [9]. Because the direct load to the column's corners causes the stress concentration producing damages and cracks, thus two phases were adopted for reducing the stress concentration or strengthening the corners of the columns using ferrocement. It concluded that the specimens with single layer ferrocement and with extra two layers at the corners have the highest ultimate axial deflection, and load carrying capacity. Then phase two showed it is more effective in strengthening the column corners using ferrocement [10]. In the conventionally jacketed specimens, the failure occurs earlier due to the stress concentration at the corners, top, and bottom. Advanced jacketed specimens and the conventional jacketed specimen had approximately the same values of the ultimate load capacity, the capacity of energy absorption, and axial stiffness, unlike the center jacketed specimens, only slight enhancement is there comparing to the control specimen [11].

The volume fraction and the number of wire mesh layers are important factors to consider in the enhancement of the specimens such as the load carrying capacity, and the axial deformation increases with the increase of the number of ferrocement layer and decreases with the increase of the aspect ratio and the preloading fraction [12]. The effectiveness, strength, and the stiffness of the ferrocement is increased with the increase in the mortar strength, the number of mesh layers, as well as the ferrocement thickness [13]. It concluded that the columns retrofitted with a single layer and double layer having an increase in load carrying capacity by 15.31% and 31.35% respectively with comparing to the control columns. When the load carrying capacity increases, therefore, the deflection is decreased by 53.5% and 64.68% for single and double layer respectively compared to the control columns [14]. In another study, it resulted that the strength of confined columns is higher of 30.6% than the unconfined columns of 8.75% of the control columns and the axial stress, ultimate lateral strain and the ultimate axial strain of the double layer columns is higher than the single layer and control column specimens [15].

The ferrocement is an alternative repair material that improved its efficiency in the construction field as it is currently used to strengthen the reinforced concrete structural members because of its ease in application and low cost [16]. The researches approved the effectiveness of the ferrocement jacketing for rehabilitation purpose in which the load carrying capacity and the axial stiffness of the damaged or preloaded columns can be easily enhanced using this technique [17]. In literature, the ferrocement when compared with other retrofitting jacketing technique such as Wire mesh mortar jacketing (WMM) is preferable when more energy absorption required and the Steel Cage Mortar jacketing (SCM) technique preferred where more strength is required [18].

Further investigations on the effectiveness of the ferrocement were made such in case of beam-column-joint was it observed that no de-bonding was observed in the retrofitted reinforced concrete beam-column joints. When comparing it observed the increase of the load carrying capacity of the retrofitted RC joints with respect to the control RC specimen [19]. Also, the utilization of industrial waste can be beneficial to the environment such as using the alkali-activated slag (AAS) in ferrocement jacketing for strengthening the specific type of building which are reinforced concrete buildings in the coastal areas where the corrosion of reinforcement is very high and dangerous. It concluded that the strengthened corroded columns by AAS ferrocement have an increment in their loading capacities and ductility such that it recovered 97 % of the original level of their capacities [20].

1.3. Finite Element Method

There are many applications of the finite element method, it can be used for solving different partial equations, and it's highly applicable and recommended for the physical domains such as structural, Electromagnetic, thermal, fluid, and other domains. In this study ANSYS19 software is used for the method implementation. In this study the finite element method is adopted in structural domain to investigate the behavior of a structure which be directly known and analyzed using analytical simulations.

1.4. Aim and Scope

The retrofitting technique using ferrocement is an important technique that should be in consideration during strengthening of RC building members or in the construction stage itself. There are many RC buildings in Oman losses their strength due to many factors such as aging of building, materials corrosion, change the building use, improper design. There is also an environmental factor such as the natural disasters and earthquakes which is unexpected, and the Oman governments should keep this in mind and consider adopting such techniques from the begging [4].

The aim of this study is to identify the effectiveness of ferrocement in enhancing the strength of the existing RC column.

The main objectives are to examine the ultimate load carrying capacity of the RC column under virgin condition.

- To examine the ultimate load carrying capacity of the RC column strengthened with ferrocement full wrapping and strip wrapping.
- To understand the deflection response of the un-strengthened and strengthened RC columns.
- To identify the mode of failure and crack pattern of un-strengthened and strengthened RC columns.
- To examine the ductility of the RC column strengthened with ferrocement full wrapping.
- To bring out the advantage of using ferrocement full wrapping.
- To compare the experimental result with the numerical simulation analysis.

2. Methodology

This part of the report presents the methodology and the experimental setup that has been implemented during the investigation of the ferrocement effectiveness as a retrofitting material full wrapping and strip wrapping for RC short columns and comparing it with un-retrofitted RC columns. The methodology for this research paper prepared as two studies, the preliminary study where all the used materials tested, and all the column specimens cast. Then the main study is the stage where twelve specimens retrofitted using different volume fraction of pre-woven mesh (PWM).

2.1. Experimental Program

The experimental program includes both studies. The properties of materials used like cement, fine aggregate, coarse aggregate, and the reinforcement (steel bars) are all determined by conducting the required materials tests. The size of the short RC column specimens is 150×150×450 mm. All specimens prepared using C30 grade concrete, 4 numbers of 8mm diameter longitudinal bars with 6 mm diameter ties at 75 mm c/c. The reinforcement details of the columns are shown is Figure 1. The Table 1 below presents the materials properties used in the concrete mix preparation.

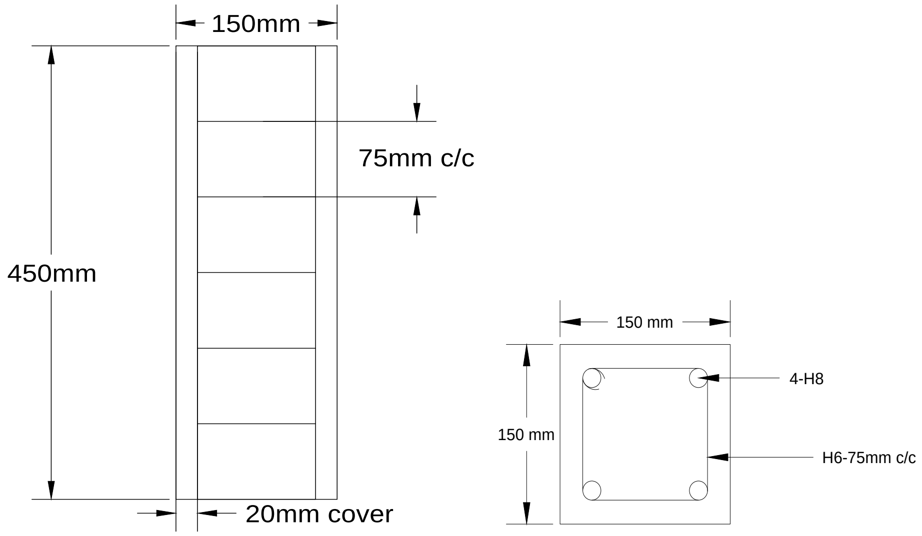


Figure 1. The Columns Reinforcement Details

Table 1. Materials Properties

Materials	Materials properties	
Cement-OPC	Specific gravity	3.15
20 mm CA	Specific gravity	2.7
10 mm CLS	Specific gravity	2.69
5 mm CWLS	Specific gravity	2.69

After the concrete mix preparation, fresh concrete tests implemented; the slump test and the concrete cube tests. The concrete kept for settlement for 60 min and the slump test was adopted at each 30 min. Table 2 shows the slump result.

Table 2. Slump test result

Time	Slump
Initial	230
@ 30 min.	190
@ 60 min.	170

The average compressive strength of the concrete cube from the test for 7 and 28 days are 22.58 N/mm^2 and 33.06 N/mm^2 respectively. The mix design proportion of C30 grade concrete is 1:1.9:2.36:0.44 as cement, FA, CA, and water respectively. The specimens were designed as RC control columns and retrofitted columns with full wrapping and strip wrapping technique using ferrocement (mesh with cement mortar). Four columns were cast and designed as control columns in virgin condition. The retrofitted columns categorized into two groups based on the retrofitting technique of the ferrocement.

For the retrofitted columns, the full wrapping technique retrofitted as per the volume fraction say 2%, 3% and 4% which gives single layer, double layer and three layers of ferrocement with pre-woven mesh respectively. For the strip wrapping technique, the columns retrofitted also as per the volume fractions 1%, 2% and 3% which gives single layer, double layer and three layers of pre-woven mesh respectively. The ferrocement wrapping technique the full wrapping and strip wrapping shown in Figures 2 and 3 respectively. Two numbers of specimens were cast for each type with total twelve columns. Table 3 shows the columns description. The pre-woven mesh was fixed to the columns using shear key, and cement sand mortar with proportion 1:2 and 0.5 w/c were applied to the all four sides.

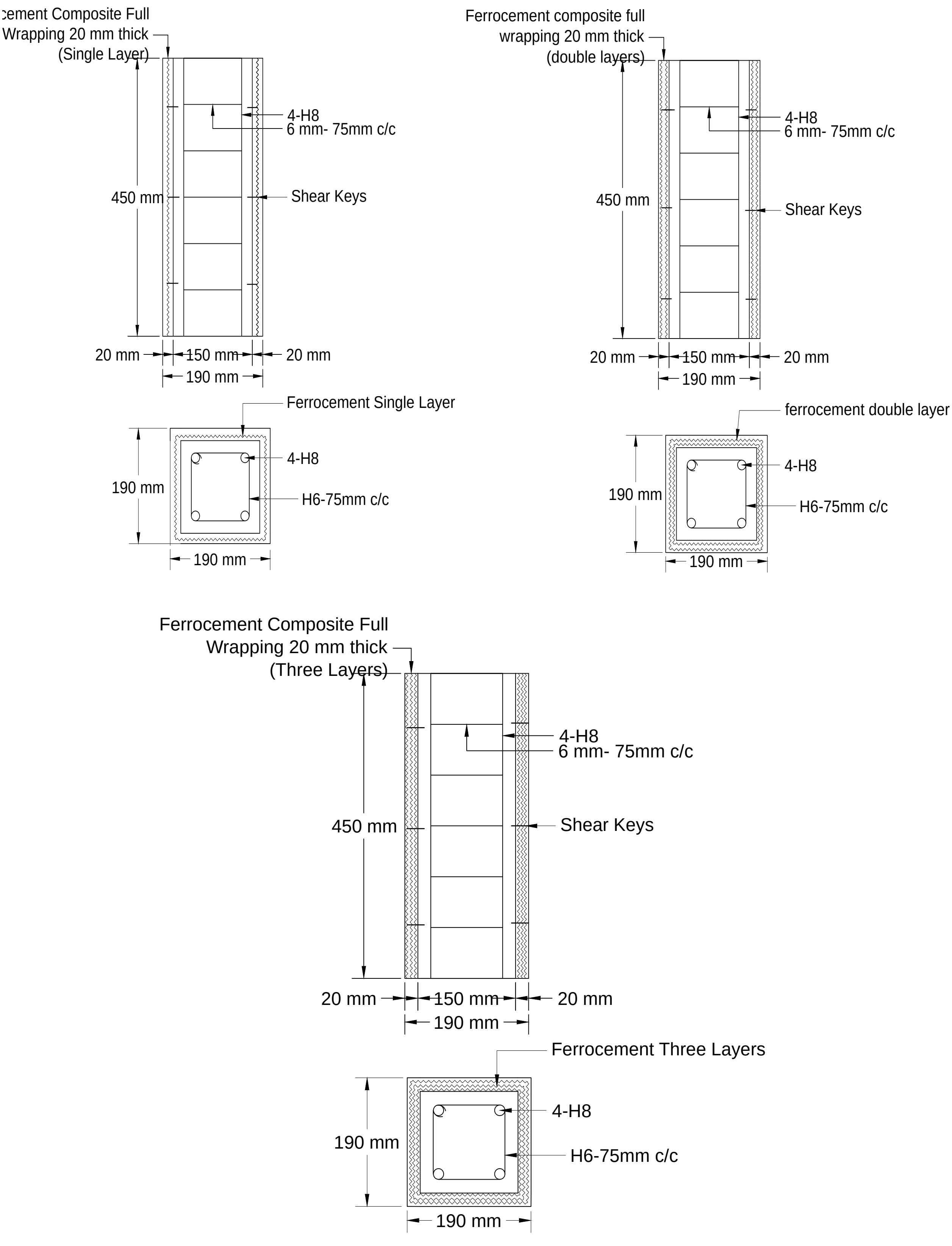


Figure 2. Full Wrapping Technique Details

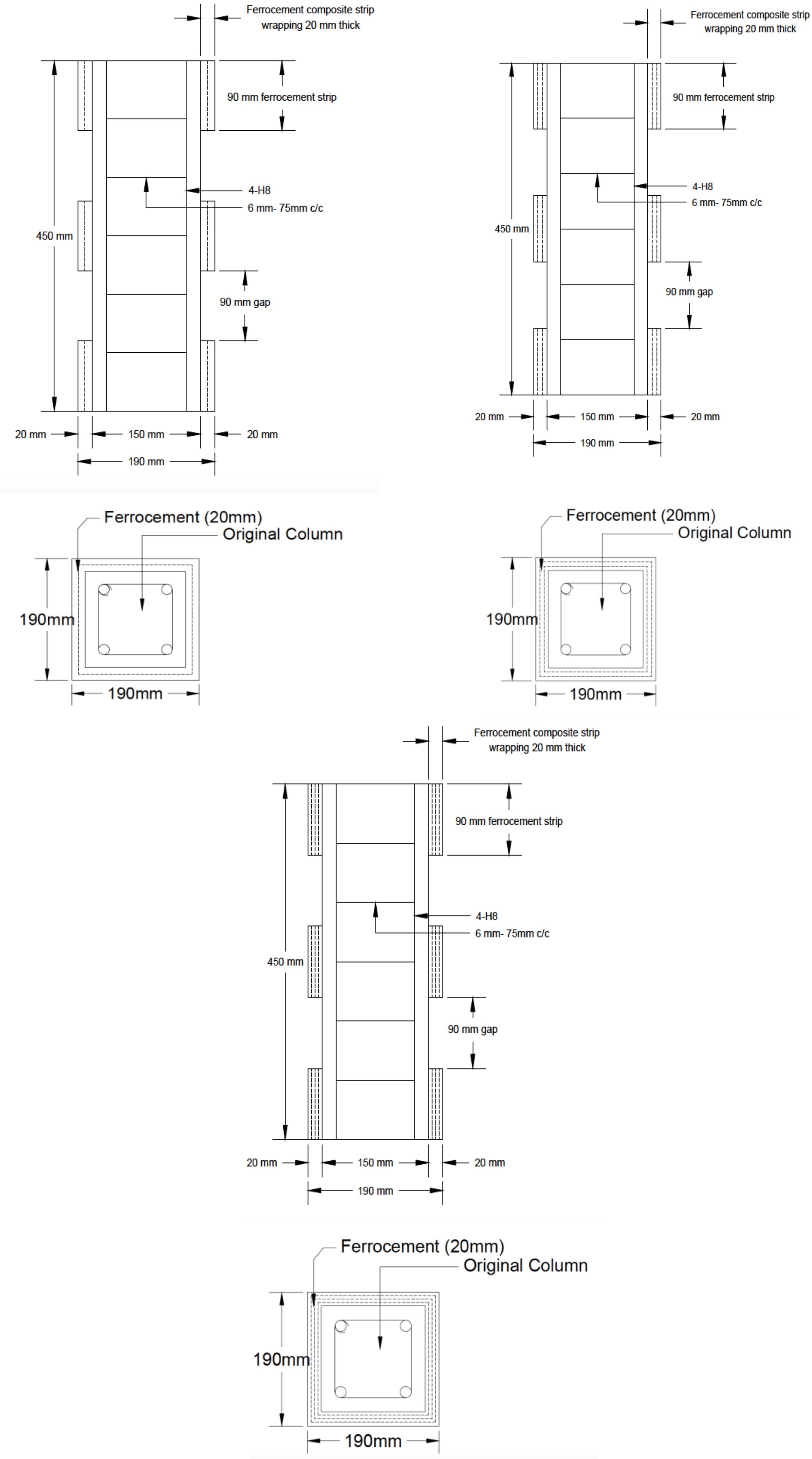


Figure 3. Strip Wrapping Technique Details

Table 3. Columns Description

Group	Specimen	Column Description
Group 1- Control Columns	CC1	Control Column at Virgin Condition 1
	CC2	Control Column at Virgin Condition 2
	CC3	Control Column at Virgin Condition 3
	CC4	Control Column at Virgin Condition 4
Group 2- Full Wrapping	FWC1-1	Full Wrapping Retrofitted Column with single layer PWM 1
	FWC1-2	Full Wrapping Retrofitted Column with single layer PWM 2
	FWC2-1	Full Wrapping Retrofitted Column with double layer PWM 1
	FWC2-2	Full Wrapping Retrofitted Column with double layer PWM 2
	FWC3-1	Full Wrapping Retrofitted Column with three-layers PWM 1
	FWC3-2	Full Wrapping Retrofitted Column with three-layers PWM 2
Group 3- Strip Wrapping	SWC1-1	Strip Wrapping Retrofitted Column with single layer PWM 1
	SWC1-2	Strip Wrapping Retrofitted Column with single layer PWM 2
	SWC2-1	Strip Wrapping Retrofitted Column with double layer PWM 1
	SWC2-2	Strip Wrapping Retrofitted Column with double layer PWM 2
	SWC3-1	Strip Wrapping Retrofitted Column with three-layers PWM 1
	SWC3-2	Strip Wrapping Retrofitted Column with three layers PWM 2

2.2. Testing Programme

All the specimens were cured first for 28 days, and the retrofitted RC short columns specimens were cured again for 28 days after the ferrocement composite application. Once the specimens removed from the curing tank, all the specimens are air dried before the testing program. The dimensions of all the specimens are measured again to ensure that the specimen's dimensions are not changed due to the ferrocement composite wrapping (length). The machine used for testing is Universal Testing Machine (UTM) with 1000 kN capacity, which is connected to a computer-controlled system. The UTM is prepared to be used. The top and bottom platform of the UTM is cleaned, and their verticality is checked to get good load concentration without obstacles. Then the specimens are installed at the machine and aligned to the loading axis and axially loaded as shown in Figure 4. The test is started after ensuring the position of the column, and the effectiveness of the system connected to the UTM. The load carrying capacity, stiffness, and the crack patterns was absorbed and recorded during the test.

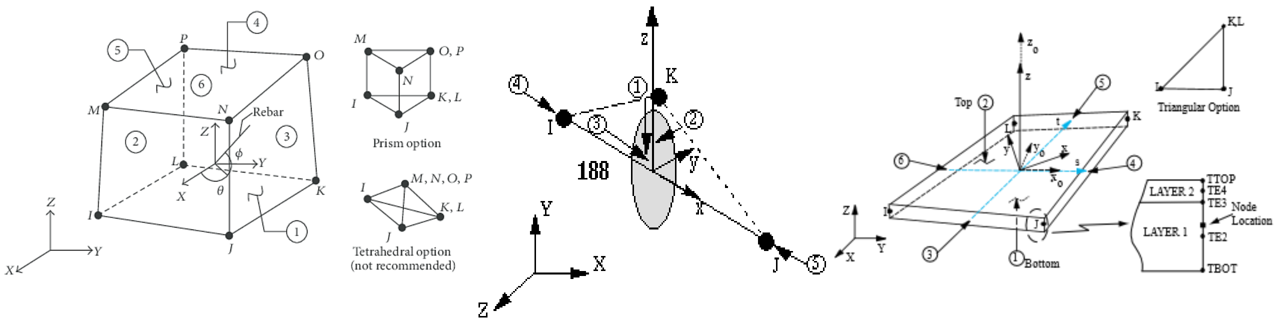
Figure 4. Specimens testing

2.3. Numerical Simulation

The finite element package in the ANSYS19 software is used to study the effectiveness of strengthening axially loaded RC short column using ferrocement full wrapping. There are many elements and links based on the materials used and their properties. In this study, three elements are mainly used to presents the properties and behavior of the concrete, reinforcement and ferrocement composite as the inputs of each element is presented in Table 4. The 3-D solid element (SOLID65) is used for modeling both the retrofitting materials the ferrocement composite and the concrete. SOLID65 element is again presented in eight nodes, each node consists of three degrees of freedom, and having the ability to crush and cracking. By using the 3-D spar element (Beam 188) which has six to seven degrees of freedom at each single node, the reinforcement is modelled. Beam 188 elements allow the elastic and plastic response of the steel bars. For the wire mesh modeling the solid element used is Shell 181. The pre-woven mesh model is defined in 353 nodes and 47 elements. Shell 181 includes several properties such as creep, plasticity, stress stiffness and the capabilities of deflecting. Figure 5 shows the elements geometry used. The reinforcement grill model and the columns that has been analyzed using FEM say control columns, full wrapping column with single layer PWM, and strip wrapping column with single layer PWM are shown in Figure 6. The numerical results are then compared with the experimental result.

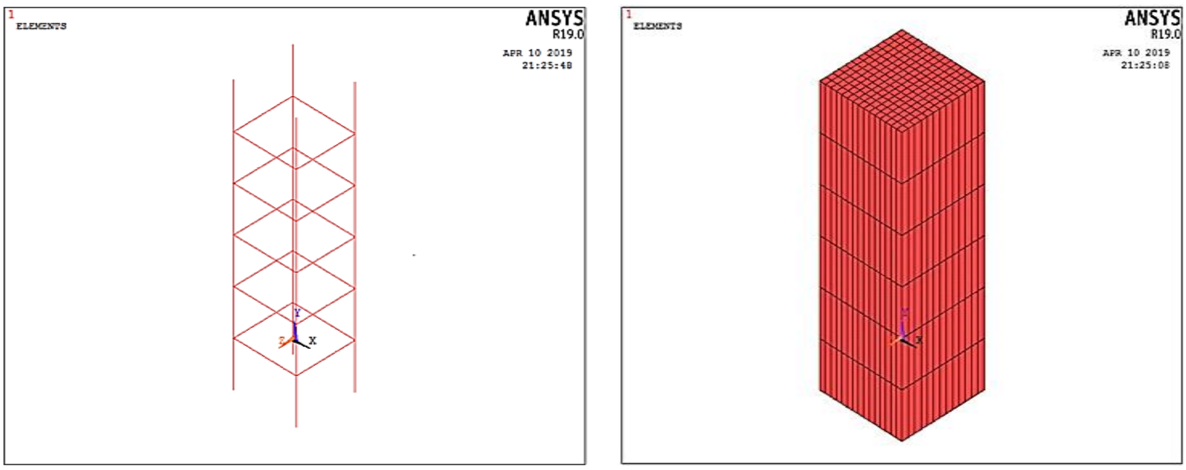
Table 4. Material Properties for the element

Material	Element Type	Mechanical Properties	
Concrete	SOLID65	Young's Modulus E	5000√33.06 =2.875×10^4 N/mm^2
		Compressive Strength f_{ck}	33.06 N/mm^2
		Passion Ratio υ	0.2
Longitudinal Reinforcement and Ties	BEAM188	Young's Modulus E	2 ×10^5 N/mm^2
		Yield Strength f_{yk}	500N/mm^2
		Passion Ratio υ	0.3
Wire Mesh	SHELL 181	Young's Modulus E	1.75 × 10^5 N/mm^2
		Yield Strength f_{yk}	370 N/mm^2
		Passion Ratio υ	0.3
		Mesh Density	2700 kg/m^3

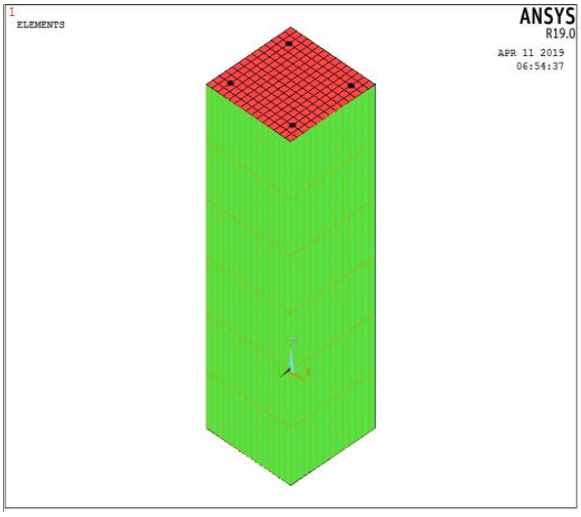


(a) SOLID 65 Geometry (b) Beam 188 Geometry (c) Shell 181 Geometry

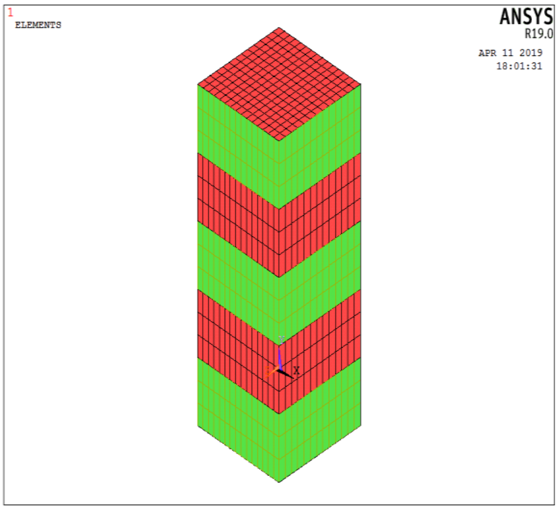
Figure 5. The elements geometry



(a) Reinforcement Grill model (a) Control Column Model



(c) Retrofitted Column Model (FWC2)



(d) Retrofitted Column Model (SWC2)

Figure 6. Columns model using FEM

3. Results and Discussion

From Table 5 below it can be seen that the result obtained from the finite element method and from the experimental investigation are almost in a good agreement since the percentage variation is less than 10%. The result from the finite element method are always expected to be more accurate using the ANSYS package. The result shows that all retrofitted specimens by ferrocement layers full wrapping and strip wrapping shows an enhancement in load carrying capacity over the control specimens.

Comparing the result of the retrofitted specimens full wrapping, group FWC2 which retrofitted by 3% of V_f shows the optimum values of load carrying capacity comparing with 2% and 4% V_f. And comparing the result of the retrofitted specimens strip wrapping, group SWC2 which retrofitted by 2% of V_f shows the optimum values of load carrying capacity comparing with 1% and 3% V_f. The deflection of the retrofitted specimens is decrease. The crack pattern of the retrofitted specimen's full wrapping is started to appear at the exact center of the column sides and the ferrocement cover does not fall off from any side. In the strip wrapping retrofitted specimens, the crack pattern started from the top of the specimen and the ferrocement cover has splitted out from the RC column. In the control specimen the crack pattern begins from the top edge of the column and the concrete surface fall off in the crashed zones.

3.1. Load Carrying Capacity

The purpose of this study is to prove the effectiveness of the ferrocement composite as a retrofitting material to strengthen a RC short column. The load carrying capacity is an essential parameter to check the effectiveness of the ferrocement composite in this study in which it indicates how much the column can withstand the load till failure point (Tables 5 and 6). The load carrying capacity of the control specimens is calculated theoretically in addition to the experiment result. The load carrying capacity calculated as per EC2 as follow:

$$\mathit{Ultimate\ Load\ Carrying\ Capacity}:\ N_{ed} = 0.567\, f_{ck}\, A_c + 0.87\, f_{yk}\, A_s$$

Where;

N_{ed} Load carring capacity;

f_{ck} Strenght of the used Concrete;

A_c Area of concrete;

f_{yk} Yield strength of the steel reinforcement;

A_s The area of the longitudinal reinfrocement used.

According to the data selected and obtained in the methodology part, the load carrying capacity of the control columns is 470 kN, calculated as shown below [21].

$$N_{ed} = 0.567 \times 30 \times 150 \times 150\ + 0.87\ \times\ 500\ \times \pi\ \times\ 8^2 = 470\ \text{kN}$$

Table 5. Experimental and numerical result of control columns and full wrapped

Group	Specimen description	V_f	No of PWM layers	Experimental Result					Numerical Result using ANSYS19		Exp/ Num %	Ultimate Load Variation %
				First Crack Load (KN)	Deflection (mm)	Ultimate Crack Load (kN)	Deflection (mm)	Average Ultimate load carrying capacity (kN)	Ultimate Crack Load (kN)	Deflection (mm)		
CC	CC-1	0	0	106.2	2.2	387	6.2	460.85	500	12.4	92.17	7.83
	CC-2	0	0	123.3	5	534.7	12.5					
FWC1	FWC1-1	2%	1	245.4	2	587.3	4.5	553.95	600	12.9	92.32	7.67
	FWC1-2	2%	1	231.3	3.1	520.6	4.3					
FWC2	FWC2-1	3%	2	296.6	3	664.3	9.0	702.1	-	-	-	-
	FWC2-2	3%	2	301.7	3.5	739.9	8.6					
FWC3	FWC3-1	4%	3	231.3	2.3	538.3	5.0	578.85	-	-	-	-
	FWC3-2	4%	3	254	2.7	574.4	4.9		-	-	-	-

Table 6. Experimental and numerical result of control columns and strip wrapped

Group	Specimen description	V_f	No of PWM layers	Experimental Result					Numerical Result using ANSYS19		Exp/ Num %	Ultimate Load Variation %
				First Crack Load (KN)	Deflection (mm)	Ultimate Crack Load (kN)	Deflection (mm)	Average Ultimate load carrying capacity (kN)	Ultimate Crack Load (kN)	Deflection (mm)		
CC	CC-1	0	0	90.4	1.4	395.7	4.3	460.2	500	12.4	92.04	7.96
	CC-2	0	0	105.3	1.5	524.7	4.6					
SWC1	FWC1-1	1%	1	168.0	1.5	524.9	4.9	514.6	550	11.68	99.32	6.44
	FWC1-2	1%	1	175.3	1.5	485.3	4.9					
SWC2	FWC2-1	2%	2	231.4	1.8	581.1	6.7	575.25	-	-	-	-
	FWC2-2	2%	2	199.2	1.7	569.4	6.5					
SWC3	FWC3-1	3%	3	177.0	1.6	499.1	5.3	490.25	-	-	-	-
	FWC3-2	3%	3	183.2	1.55	485.4	5.4		-	-	-	-

The average load carrying capacity of the control columns CC from the experimental program identified as 460.52 kN in which it's approximately similar to the calculated load carrying capacity as per EC2. The load carrying capacity of the control columns CC shows the minimum load carrying capacity compared to the retrofitted columns FWC and SWC.

Finally, the load carrying capacity of the retrofitted column increases because of the ferrocement capability of load absorption and load confinement. The transvers reinforcement which surrounds the longitudinal reinforcement is contributes in the load confinement. The confinement zone in the column takes its shape according to the transvers reinforcement type. The free zone in the column in Figure 7 is the weakest zone of the column. The extension on the ties as shown in Figure 8 helps the column to stay in its shape by supporting the longitudinal bars and contribute in preventing the column buckling. The tie extension is calculated as d010 in which d0 is the diameter of the reinforcement used. The transverse reinforcement also resists the shear failure and stress and confine the concrete core which give the column sufficient deformability.

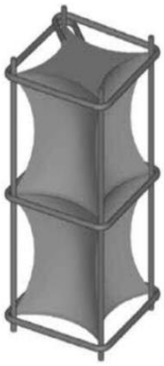


Figure 7. Columns load confinement

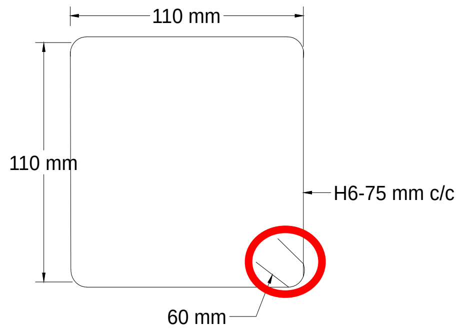


Figure 8. Reinforcement tie extension

Comparing the retrofitted columns with full wrapping together the specimens with 3% volume fraction shows the highest enhancement between all the specimens. From the result it is concluded that the retrofitting of the RC short columns using ferrocement composite is an effective technique in the strength enhancement and the retrofitting of 3% volume fraction shows the optimum result as shown in the graphical representation in Figure 9.

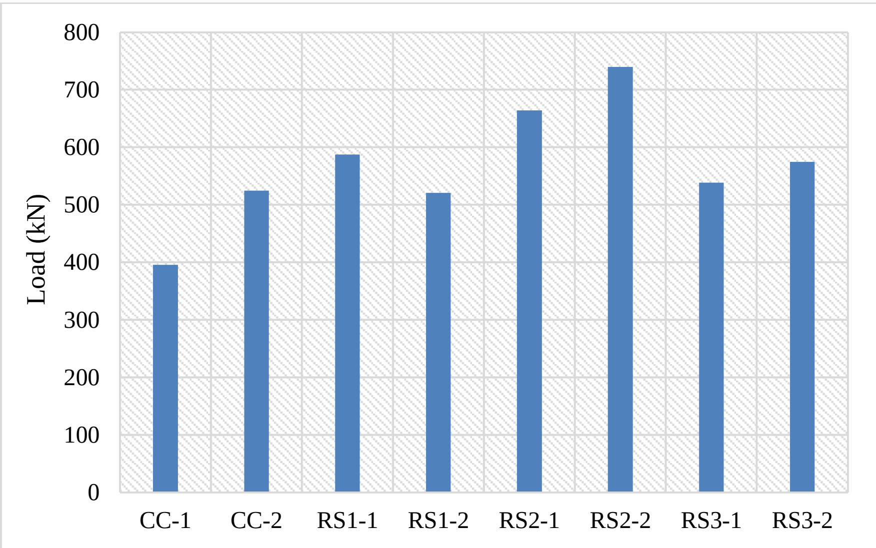


Figure 9. Load carrying capacity of control and retrofitted columns with full wrapping

Thus, the load deflection response for the control columns and retrofitted columns with strip wrapping is shown in Figure 10.

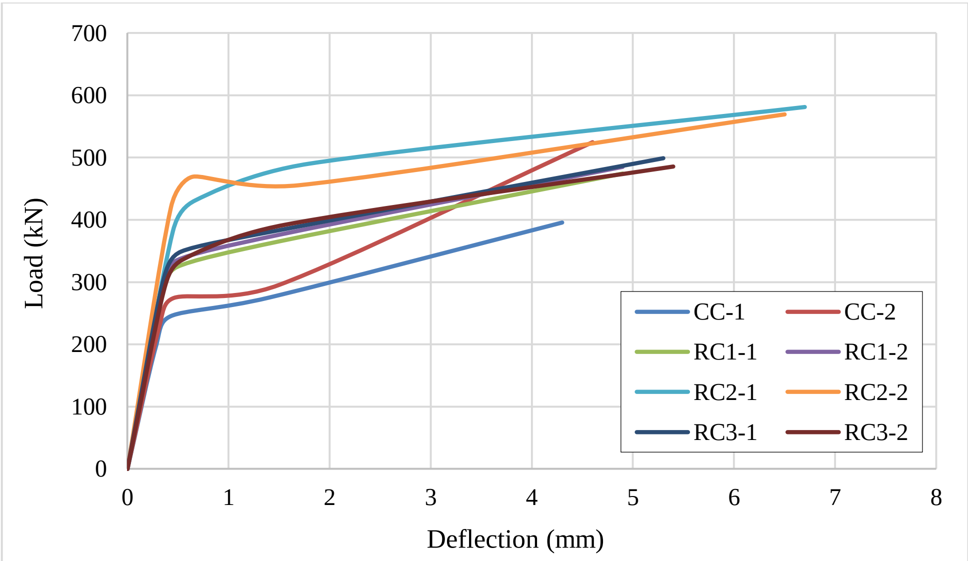


Figure 10. Load Carrying Capacity of control and retrofitted columns with strip wrapping

3.2. Deflection

Deflection of the column is always parallel to the load carrying capacity. When the load increased, the deflection also increased along with it. In this study, the deflection at the same load level is decreased in the case of full wrapping retrofitted columns with 3% Vf compared to the control columns (CC) by 50 to 60 percent. In case of strip wrapping the deflection is decrease by 30% when the column retrofitted with 2% V_f. The average deflection value of the control columns is the highest deflection among all the specimens because of the parallel relationship with the load. Retrofitting the RC short columns with the ferrocement composite makes this relationship between the deflection and the load carrying capacity somehow acts differently.

The deflection, ductility factor of the columns is calculated as shown in Table 7 which is known as the ratio of the ultimate load carrying capacity to the yield load when the first crack occurs. The ductility factor for the control columns CC is higher than the retrofitted columns which is due to the behaviour of the retrofitted column that leads to the reduction of yield deflection and enhances the confinement of the column.

Table 7. Experimental and derived information for control and retrofitted columns both full and strip wrapping

Group	Specimens Description	V_f	No of PWM Layers	First Crack Load (Yield deflection) (kN)	Deflection (mm)	Ultimate Crack Load (kN)	Deflection (mm)	Average Ultimate Load Carrying Capacity (kN)	Deflection Ductility Factor
CC	CC-1	0	0	106.2	2.2	387	6.2	460.85	3.6
	CC-2	0	0	123.3	5	534.7	12.5		4.3
FWC1	FWC1-1	2%	1	245.4	2	587.3	4.5	553.95	2.4
	FWC1-2	2%	1	231.3	3.1	520.6	4.3		2.2
FWC2	FWC2-1	3%	2	296.6	3	664.3	9	702.1	2.2
	FWC2-2	3%	2	301.7	3.5	739.9	8.6		2.4
FWC3	FWC3-1	4%	3	231.3	2.3	538.3	5	578.85	2.3
	FWC3-2	4%	3	254	2.7	574.4	4.9		2.3
SWC1	SWC1-1	1%	1	168.0	1.5	524.9	4.9	460.2	3.1
	SWC1-2	1%	1	175.3	1.5	485.3	4.9		2.8
SWC2	SWC2-1	2%	2	231.4	1.8	581.1	6.7	514.6	2.5
	SWC2-2	2%	2	199.2	1.7	569.4	6.5		2.8
SWC3	SWC3-1	3%	3	177.0	1.6	499.1	5.3	575.25	2.8
	SWC3-2	3%	3	183.2	1.55	485.4	5.4		2.6

4. Conclusions

In this study, the RC column retrofitting techniques were adopted with the help of ferrocement composite to enhance the load carrying capacity. Based on the experimental data and numerical simulations using ANSYS 19, the following results are drawn.

- The ferrocement retrofitting system using pre-woven mesh with mortar can be used as an effective technique in the strengthening of RC short columns in which the load carrying capacity of the column can be enhanced. All retrofitted specimens with ferrocement full wrapping and strip wrapping recorded a higher load carrying capacity over the control specimens in the virgin condition. The retrofitting using full wrapping technique is more effective than the strip wrapping technique and easier to be adopted.
- The retrofitted specimens with 2%, 3% and 4% V_f with full wrapping shows an improvement in the load carrying capacity of about 17%, 35% and 21% more compared to the control specimens respectively. Among the three different V_f say 2%, 3% and 4%, the V_f =3% is optimum in all aspects.
- The retrofitted specimens with 1%, 2% and 3%V_f with strip wrapping shows an improvement in the load carrying capacity of about 11% , 20% and 6% more compared to the control specimens. Among the three different volume fractions say 1%, 2%, and 3%, it is found that 2% volume fraction perform well when compared to the other two volume fraction.
- The retrofitted columns with full wrapping and strip wrapping at the optimum volume fractions shows decreased deflection with respect to control column at the same load level by 50 to 60% and 30% respectively.
- The full wrapping technique with one layer of PWM gives more load carrying capacity compared to the strip wrapping by 7%.The full wrapping technique with two layers of PWM gives more load carrying capacity compared

to the strip wrapping by 18%.The full wrapping technique with three layers of PWM gives more load carrying capacity compared to the strip wrapping by 16%.

- The cracks in the strengthened RC column with ferrocement full wrapping and strip wrapping occurred in crushing mode of failure and none of the columns exhibits brittle or premature failure.
- The numerical method using ANSYS19 gives a good agreement between experimental results and the variation not more than 10%.

5. Conflicts of Interest

The authors declare no conflict of interest.

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